Genetic Basis of Morphological Variation

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Genetic Basis of Morphological Variation

AN EVALUATION AND APPLICATION OF THE TWIN STUDY METHOD

By Richard H. Osborne and Frances V. De George

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Foreword

Nature-nurture polemics are no longer quite as rife as they used to be during the period between the two world wars. Nevertheless, the question of the relative contributions of heredity and environment to the causation of the differences between persons remains one of the outstanding unsettled problems of the Science of Man The diversity of opinion continues to be as great and irreconcilable as ever Only a few years ago Darlington was able to write "Man is immensely adaptable, not through the plasticity of the individual but through the variability of the species .. Individual adaptability is indeed one of the great illusions of common sense observation " At the opposite extreme, Alfred Adler wrote "But the concept that character and personality are inherited from one's parents is universally harmful because it hinders the educator in his task and cramps his confidence." And yet, is this so intractable an issue that it must remain outside the framework of scientific analysis? Obviously it need not be, but the only hope of arriving at an universally satisfactory settlement lies in acquisition of well authenticated evidence, not in declarations of personal opinions, however uncompromisingly or persuasively stated Careful gathering of reliable data was the goal which Osborne and De George set for themselves, and their book reports the results so far obtained

The naive hope that some day we shall know which human "traits" or "characters" are hereditary and

which are environmental is no longer entertained by any informed student of the problem. More sophisticated approaches had to be adapted All traits and all characters are hereditary and all are environmental; there is no organism without heredity, and no heredity can produce an organism except by transforming a part of the environment into a living body, the path which the development of the body takes is necessarily within the norm of reaction of the organism, set by its genotype but realized within a given succession of environments. The nature-nurture problem takes, then, a different form We must ask what portion of the variance in a given trait observable in a given population is ascribable to the existing diversity of genotypes and what part can be accounted for by the diversity of environments This statistical approach is adopted by Osborne and De George. The critical value is everywhere the ratio of the variances observed between members of monozygotic twin pairs and between those of dizygotic twin pairs. These "intrapair" variances are, in turn, compared with the "interpair" variances, which measure the diversity of the forms which a given trait takes in the population from which the twins studied are a sample.

Some of the results obtained by Osborne and De George can be understood properly only in the light of the principle that what is inherited is the norm of reaction to the environment, and not this or that "character." Thus, Osborne and De George have found no appreciable genetic components in the variability of such traits as the body weight, the head length, and some measurements taken transversally to the long axis of the body Other studies on twins, particularly the classic work of Newman, Freeman, and Holzinger, have found a strong genetic component in the same characters And yet, there is no contradiction between these studies. It turns out that a considerable proportion of the twins studied by Newman, Freeman, and Holzinger were young people still in the process of growth, while Osborne and De George have dealt with adult twins The most reasonable explanation is, consequently, that the genetic components in the determination of the growth rates and growth patterns are relatively greater than those in the conformation of the fully developed traits in the adult.

The work of Osborne and De George represents a great step forward in the studies on the nature-nurture problem. Surely, much further work is needed, the data which they have collected will however remain a part of the store of factual evidence, as well as an example of how such evidence should be gathered and analyzed.

Theodosius Dobzhansky
Columbia University, New York

Preface

The study reported here explores the possibilities of investigating the important question of genetic and environmental interaction by genetic methods utilizing the techniques of morphological description and measurement.

The complex nature of man's genetic variation and some of the problems which are unique to human studies are reviewed The twin method is then evaluated, within the context of our understanding of the phenomenon of human twinning, for its usefulness in detecting genetic variability and analyzing genetic and environmental interaction. With this background, the twin method is then applied to the study of different descriptions and measurements of morphological variation

Because this is a preliminary study, emphasis has been placed upon the methods of investigation and upon providing an empirical basis for the application of genetic and morphological studies to different human problems It is hoped that the methods presented here and the results of this analysis will suggest further twin research and morphological studies in genetics, anthropology, and the medical sciences.

While the present study was designed for the analysis of genetic and environmental effects on what may be termed "normal" morphological variation, selection of the subjects on the basis of medical histories and examinations has made it possible to extend considerably the scope of the investigation. Most of the data relat-

ing to medical information have been reported elsewhere Those aspects which have a bearing on the evaluation of the twin method or the analysis of morphological variables are reported here. Extensive data available from the records of the Columbia-Presbyterian Medical Center also have been incorporated

The Twin Study Project was carried out under the auspices of the Institute for the Study of Human Variation in Columbia University, and was conducted within the facilities of the Columbia-Presbyterian Medical Center. The collection of the data was started in September 1952 with a poll of all new admissions to Vanderbilt Clinic, for twins, it was completed in March 1956.

R. H. O.
June, 1959 F. V. De G.

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The subjects were examined in the Constitution Laboratory in the Department of Medicine, College of Physicians and Surgeons, Columbia University Dr William Sheldon and his staff were helpful in executing procedures pertinent to this phase of the study. Dr. Sheldon assigned the somatotype ratings and made valuable control data available for the

analysis of body build Dr Sylvia Traube was particularly helpful in expediting various study procedures and in making arrangements for the study subjects. Miss Edith Seabury gave generously of her time in obtaining questionnaire information

The medical aspects of this study profited greatly from the advice and assistance of Dr Sylvia Traube, Dr Albert Damon, and Dr Warner Nash, who, in addition to other staff residents, conducted the medical examinations of all of the subjects studied Clinical laboratory determinations were performed primarily by Miss Ellen Mikkelson and Miss Betty Nielson

The juvenile series was obtained from the Fetal Life Study conducted in the Department of Pediatrics, Columbia University, College of Physicians and Surgeons, and Babies Hospital This study was aided by grants from the Rockefeller Foundation, the Life Insurance Medical Research Fund, the New York State Department of Health, the New York Foundation, The Association for the Aid of Crippled Children, and the U.S Public Health Service (Grant G-4194).

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Genetic Study of Morphological Variation

Genetic study of morphological variation is a study of complex multifactorial inheritance, which has for the greater part been avoided in human genetics In science, however, solutions must be sought for even the most elusive problems, and the time has come when complexly inherited traits and the intricacies of heredity and environment interactions cannot be avoided in genetic studies of man In order to evaluate genetic methods for studying the more complex part of human variation, and for investigating heredity and environment interactions, we shall first take into account the development of methods in human genetics and the types of problems for which these methods are designed.

The science of genetics is based upon the theorem that inheritance is particulate and upon Mendel's demonstration that the hereditary units which determine recognizable differences in phenotypic characters will segregate in a predictable fashion. These principles having been granted, it follows that the products of inheritance themselves become predictable. Thus when Sutton (1903) presented evidence for the relations between chromosomal segregation and assortment at meiosis and the segregation and assortment of inherited qualitative differences, a satisfactory explanation was provided for the physical basis of inheritance and for the mechanism by which hereditary factors are distributed At the

time of these early beginnings of the modern science of genetics, the only alternative to these satisfying and experimentally workable principles was a theory of blending ancestral inheritance. Evidence for this latter theory depended upon biometrical and statistical treatment of continuous and quantitatively varying differences While Galton and Pearson had been able to demonstrate by family studies that this type of variability was at least in part inherited, they could not advance a satisfactory theory for *the mechanism of hereditary transmission* from one generation to the next, nor could they match the predictability levels of the Mendelian geneticists.

Even today the particulate theory of inheritance and the existence of chromosomal determinants are inferences drawn from observations of Mendelian segregation It is not surprising, therefore, that at the beginning of the science of genetics, inheritance was equated with discrete or qualitative changes and that interest was focused almost exclusively upon variations of a discontinuous nature which gave the clearly discernible segregations seemingly demanded by this theory. In the conflict which developed between Mendelian geneticists and biometricians, discontinuous variability was viewed as being of an entirely different nature from that of continuously graded or quantitative variation The two "types" of variability, as well as the two theories, were viewed as alternatives.

After Nilsson-Ehle and Johannsen in 1909 independently demonstrated that both genetic and non-genetic quantitative variability could be identified in the same character, it was evident that genetic influences could be distinguished from environmental modifications, and that heredity plays a role in determining quantitative or continuously graded differences. In 1918 R A Fisher proposed a method for analyzing such continuously varying characters "*on the supposition of* Mendelian inheritance." Evidence for this supposition has been extensively provided, as for example by Karl Sax (1923) when he was able to show linkage between marker genes and genetic factors producing quantitative effects. Although the controversy as to whether continuous or quantitative variability could be inherited was ended, a tendency has persisted to consider variability as a dichotomy, continuous vs. discontinuous This tendency, together with certain limitations of interest, have had an important bearing upon the present development of human genetics

One of the first and main points of disagreement about these two supposedly different types of variability was their relative importance in evolutionary change Darwin and his followers considered small fluctuating and continuously varying differ-

ences to be the building blocks of adaptation and evolution. The opposing view of the mutationists, which was formulated in large part by de Vries (1901), maintained that evolution proceeded by large and drastic mutational stages or steps of qualitative change. The theory that discontinuous or qualitative evolutionary changes resulted from discrete mutations appealed to the Mendelian geneticists as being compatible with their particulate theory of inheritance. These Darwinian and mutational theories of evolution are still subjects for discussion, but with the gradual filling in of the paleontological record and the development of population genetics, there is less need to account for sudden evolutionary changes or for large and drastic mutational stages (Dobzhansky, 1951, 1955, Mayr, 1942, Schmalhausen, 1940, Simpson, 1949, 1953). Darwinian views are now recognized as compatible with the principles of modern genetics, and a synthesis is taking place between concepts that had at one time been considered diametrically opposed. The basis of this synthesis is summarized in a single statement by Dobzhansky (1955) "Evolution is a gradual and continuous process, but it results from the summation of many discontinuous changes, mutations, a great majority of which are small "

This long-continued controversy as to types of variability results in large part from the all too common failure to distinguish clearly between determinant and effect, genotype and phenotype. The idea of a gradual and continuous process of evolution which is now acceptable to the geneticist applies to the adaptive changes of the phenotype brought about by discontinuous genotypic changes, mutations, which, though Mendelian *in nature, are small in their phenotypic* effects. The modern geneticist accepts the importance ascribed to continuous variation by Darwin while preserving the particulate theory of inheritance.[1] With the acceptance of the importance of continuous variation in evolution and its compatibility with genetic principle, it is now possible through the study of evolutionary problems to add greatly to our understanding of genetic variability.

Evolution may be described simply as adaptive genetic change under natural selection The adaptiveness of any genetic determinant is the consequence of its influence on the phenotype and of the integration of this effect into the total complex of characters which make up the whole functioning organism. Therefore, it is ultimately the total genetic consti-

[1]Julian Huxley (1926), who has contributed so much to genetic and evolutionary theory, in a review of Morgan's *The Theory of the Gene*, which he entitled "A Static Theory of Heredity," made the following prophetic statement "It may be that with further analysis the antinomy between mutation and continuous variation will be shown to have rested on utterly false bases!"

tution of the organism which is of evolutionary importance Geneticists have come to recognize that even when they are studying a hereditary character showing a fairly simple and discontinuous expression, it is never possible to deal with a single isolated genetic factor, but rather with the entire genetic "reaction system" (Schmalhausen, 1949). These balanced reaction systems have been selected to buffer or protect the organism against the shock of drastic genetic or environmental change. Therefore under natural conditions individuals having such genetic protection will have the greatest chance of survival and of assuming an evolutionary role Though couched in different terminology, these principles and the potential importance of their effects upon human variation were recognized by Darwin

> With respect to the causes of variability, we are in all cases very ignorant, but we can see that in man as in the lower animals, they stand in some relation to the conditions to which each species has been exposed, during several generations Domesticated animals vary more than those in a state of nature, and this is apparently due to the diversified and changing nature of the conditions to which they have been subjected In this respect the different races of man resemble domesticated animals, and so do the individuals of the same race, when inhabiting a very wide area like that of America . it is, nevertheless, an error to speak of man, even if we look only to the conditions to which he has been exposed, as "far more domesticated" than any other animal .... in another and much more important respect, man differs widely from any strictly domesticated animal; for his breeding has never long been controlled, either by methodical or unconscious selection . . If we consider all the races of man as forming a single species, his range is enormous . it is a well known law that widely ranging species are much more variable than species with restricted ranges, and the variability of man may with more truth be compared with that of widely ranging species, than with that of domesticated animals
>
> Darwin (1871), "The Descent of Man and Selection in Relation to Sex" Taken from *The Origin of Species and the Descent of Man,* The Modern Library, New York, pp 415–416

Man's evolutionary history and the fact that he is a widely distributed polymorphic and outbreeding species introduce into his genetic variability the very complexities which the geneticist tries to reduce in his experimental organisms through intentional or artificial selection and inbreeding (Mayr, 1955). Consequently, human populations are more similar to natural or wild populations than to laboratory animal colonies In natural or wild populations it is necessary to deal with complex units of genetic organization, even with the whole genotype (Lerner, 1955).

Complex multifactorial inheritance, and therefore continuous and quan-

titative variation, must now be recognized not only as compatible with modern genetic theory, but also as constituting an essential part of modern theory. With this evolution in thinking, work in other areas of genetics which until quite recently has been almost totally ignored in orthodox human genetics takes on new importance Studies in polygenic inheritance have been carried out most extensively in connection with plant and animal breeding, where for most practical problems it is necessary to deal with variation which is unquestionably of a multifactorial or continuous and quantitative nature. In this work, continuous and quantitative variation is attributed to the action of polygenes which have a minor and multiplicative or additive effect, while qualitative differences result from the action of a single or major gene. The terms major gene and polygene obviously refer to the inherited genetic determinants, which by our particulate theory of inheritance we take to be discrete or discontinuous chromosomal elements The confusion in terminology between cause and effect which has plagued the use of the terms continuous and discontinuous, or quantitative and qualitative, is avoided, and a gradation rather than a dichotomy of type is clearly implied by terms which logically translate into "one" or "many"

We cannot, however, escape the fact that hereditary determinants can only be inferred from their observable phenotypic effects, and we must thereby attach our labels of major gene and polygene in accordance with the usual criteria for qualitative or quantitative variability, between which it is not always easy to distinguish What may at first appear to be a qualitative difference may later be found to be quantitative as a more precise measure becomes available or the measuring scale is changed. A simple example is the test for taste sensitivity to phenylthiocarbamide which long provided a classroom example of a qualitative difference in man. As long as impregnated paper or pure crystals are used, the population can be divided easily into tasters and non-tasters It is now known that if solutions of various concentrations are used, taste acuity to this substance shows a continuous range from a saturated solution to dilutions of only 5 or 10 parts per million The use of a finer measuring scale, therefore, shows that a difference formerly thought to be qualitative is continuous or quantitative.

Similarly, a character which appears qualitative by one measurement will be found to be quantitative when placed upon a different kind of scale An excellent example is given by Lush (1948) in a discussion of the practical importance of this problem The colors of the spectrum when viewed by the human eye are placed

upon a qualitative scale, but, if measured in terms of the length of light waves, the scale becomes quantitative. By definition, measurable phenomena are quantitative, while those which lend themselves to classification, or to categorization, are qualitative Simple as these definitions for quantitative or qualitative, continuous or discontinuous, may at first seem, it is readily apparent that, in terms of actual phenomena, a separation of variability into these two types may be entirely artificial and arbitrary

The strict classification of a character as qualitative or discontinuous may obscure important aspects of its variability and even result in errors of genetic interpretation As Mather (1953) states, the antigenic properties are, and may be the only, discontinuous characters in man, but even they have a quantitative level. In the ABO blood group series a single genetic factor or major gene is typically responsible for classification of the type of an individual's antigenic property within this antigenic series An individual homozygous for the Type O producing factor will be classified as Type O Nevertheless, not all but only some individuals of this type can be used as universal blood donors, and considerable individual and quantitative variability is found in antibody formation and strength of reaction among Type O persons. These quantitative differences in strength of reaction can be demonstrated also for every other known blood factor. A different and even more striking deviation from the single major gene ideal of the antigenic substances which affects the total expression of a blood factor is now known. Individuals have been found who even when not homozygous for the Type O producing factor will be typed as O, and the genotype of such an individual cannot be inferred directly from his phenotype, an inference that normally is possible (Levine, 1955). More common examples of departures from the major gene ideal are the "dosage" effects which result in quantitative differences in the amount of antigenic substance present in the blood. In these instances, there is an interaction between the major genes in the heterozygous condition. This dosage effect can be found in the MN and several others of the adequately studied blood group systems (Race and Sanger, 1954)

It is now clear that the early separation of variation into two types, continuous and discontinuous, is no longer necessary in the light of modern genetic theory. As a matter of fact, it cannot be supported by actual observation. It is, of course, convenient for descriptive purposes to speak of different types of variation, but any terms so applied have meaning only when the level or nature of observation is clearly specified The greatest

usefulness in attaching such descriptive labels is to define the technique of analysis to be employed, for the methods which are the most satisfactory for analyzing simple genetic situations are quite inappropriate for use with more complex forms of inheritance For analysis of the more complex forms, the terms major gene and polygene, or even multifactorial, are probably to be preferred, as they are less liable to be misunderstood than are the terms continuous and discontinuous, quantitative and qualitative The importance of multifactorial or polygenic inheritance in man must now be recognized, both theory and observation indicate that it constitutes the bulk of genetic variation in man (Darlington, 1954; Dobzhansky, 1954, 1955, Mather, 1949, 1953, Penrose, 1949, Snyder, 1955) It follows, as has been repeatedly stressed by Snyder (as well as others) "that significant further progress in the genetic analysis of human traits depends on the development of methods which will provide information on polygenic differences information which is not obtainable from the standard techniques designed to delineate major gene differences." (Snyder, 1955).

THE METHODS OF HUMAN GENETICS

The principal methods of human genetics (pedigree analysis and the study of gene frequencies in populations) have been designed primarily for analyzing major gene differences which demonstrate more or less simple Mendelian segregations as recognized by their essentially qualitative or discontinuous effects The difficulties encountered in studying human subjects have contributed to this limitation of interest and method, since the attempt to study more complex inheritance would increase these difficulties proportionately. This limitation of method and interest and consequently of concept has been further supported by a Mendelian rationale [2] While there can be little doubt that there was great wisdom in following Mendel's model of concentrating upon genetically simple characters at the beginning, it is, as we have seen, the more complex or polygenic variation which constitutes the greater part of genetic variation in man The continued growth of the science of human genetics will depend upon development of methods for dealing with these complex genetic

[2] Stern (1949) "Mendel taught us not to attempt the study of inheritance of all the genetic differences at once, but to follow separately the inheritance of differences dependent upon single pairs of loci" (See also Neel, 1955)

problems.[3] This of course does not mean that the continued search for what may be essentially major gene differences in man is unimportant, or should be ignored, the extensive biochemical, physiological, and serological studies, which are now so popular, are particularly valuable for they will contribute information about functionally or adaptively important genetic characters which can also serve as "marker genes," the use of which will increase the precision and effectiveness of any type of genetic prediction or analysis. The methods for these studies are largely transferable from experimental genetics, however, and with the impressive progress which has already been made in their application to man, they do not pose methodological problems of the magnitude of those in the study of multifactorial or polygenic variation.

The simple Mendelian methods of analysis which worked so successfully with major gene characters do not lend themselves well to the analysis of characters which depend upon the action in more than three separate loci. This becomes particularly true if the phenotypic expression of the character is modified by environmental factors The more complex the genetic and non-genetic components of variability, the more intricate become the methods of analysis, and, consequently, the more difficult they are to apply to other than experimental organisms. The methods of analyzing multifactorial inheritance, originally presented by R. A Fisher, have now been greatly extended by Lush (1945), Mather (1949), Wright (1952), and Kempthorne (1955), as well as by others These methods, which depend principally upon correlations between relatives and upon Fisher's "analysis of variance," have been developed mainly for applying genetic principles to animal and plant breeding. In work with animals and plants, it is possible to control breed and progeny test for specific characters or attributes and for particular combinations of such characters. The further the study departs from these two basic experimental procedures, which are practical and permissible with domesticated animals, the less efficient are these statistical methods.

Before approaching the consideration of methods or procedures for analyzing polygenic variation in man, the fact that actual or planned experimental conditions can not be attained must be recognized and accepted. For a myriad of moral, social, religious, and political reasons,

[3] Dobzhansky and Wallace (1954) "The preoccupation with single gene effects was, no doubt, reasonable and expedient One learns arithmetic before trigonometry, and simple tunes before symphonies

But in science, the time usually comes when oversimplification becomes misleading and directs the thinking into wrong channels It looks as though human genetics is on the verge of this situation"

controlled breeding cannot be instituted. Even if it were possible, any type of breeding program would yield a doubtful return for both practical and genetic reasons. In addition to man's unsuitability for experimental procedures because of the length of his life span, gestation period, low reproductive rate, etc., his genetic heterogeneity, extensive polymorphism, and breeding and evolutionary history, as originally pointed out by Darwin, would render any conceivable breeding program futile.[4] Nevertheless, even though the principal element of an experimental genetic procedure of controlled breeding cannot be utilized in human genetic studies, naturally occurring situations do exist in man which can be exploited to great advantage population isolates, population migration with its concomitant intermixing of genetically different peoples, the occurrence of twins, consanguineous matings, adoption practices, and other culturally conditioned situations which are unique to man, such as his sense of family unity with the accompanying recording of biological relationships These are merely different, naturally occurring situations for which different and appropriate methods of analysis must be devised

In considering methods appropriate for the study of human genetics, which is in large part applied genetics, account must be taken of its objectives, which differ greatly from those of any other applied genetics In the usual application of genetic principle and knowledge, the object is to select and change the genetic constitution of the individual, strain, or breeding population in such a way as to produce a desired phenotype. In other words, genotypes are developed that, at least within a particular environment, will produce a specific phenotype with a characteristic quality or performance An example is hybrid corn, which is developed for different soil and climate areas to give yield and quality of a desired standard In man efforts must instead be directed toward development of a variety of physical and social environmental constellations which will permit different genotypes with limited or particular norms of reaction to produce phenotypes with a satisfactory character or performance For example, the diabetic is impaired by a failure

[4] Even sterilization of the mentally defective cannot, with our present genetic knowledge, be justified as a practicable procedure for effecting any important change in the genetic constitution of a human population In fact, by the theory of balanced polymorphism this might not be advisable in all cases even if it were practicable Eugenists must recognize that the only biological measure of adaptiveness is in terms of reproductive performance, and the solution therefore is not sterilization but correction of the social environment which places a premium upon the reproductive activity of the least desirable elements This does not mean that sterilization on the basis of an individual's genetic character may not be both justified and advisable for social and economic reasons, providing that proper attention is given to the possibility of etiological diversity as has been pointed out by Planansky (1955)

of glucose metabolism under conditions normal for the non-diabetic. By dietary control and/or insulin therapy, the ill effects of a failure of glucose metabolism are alleviated without any alteration in the diabetic's genetic endowment The ultimate would be recognition of the carrier state and of the potentially susceptible, and prevention of the expression of this unfavorable trait by either preventive therapy or marriage counseling. The primary objective in the application of human genetics is not to change but to learn how to anticipate and make the most of a given genetic constitution In medicine, eugenics, population management, or any other aspect of the human problem in which genetic factors may play an important role, the genetic method in the forseeable future must have as its goal the appropriate control or manipulation of the environment rather than the change of particular genetic determinants, whole genotypes, or the genetic character of the population.

With this objective, the genetic study of man ceases to be just "bound-up with the elucidation of the heredity-environment problem" (Synder, 1955) The interaction of heredity and environment is the problem. Unfortunately, emphasis on the study of the mechanisms for transmission and distribution of major gene differences has resulted in little experience in studying heredity-environment interactions in man If we are eventually to take advantage of man's genetic variability, as well as both the diversity and modifiability of his environment, we must increase our understanding of the interaction between heredity and environment To this end we should appraise critically our methods of studying this fundamental genetic problem

Part Two

An Evaluation of the Twin Study Method

Chapter II

Methods of Analysis

In genetic studies of man the closest approach to an experimental procedure theoretically can be made by the study of twins In theory this method also constitutes the most efficient approach for appraising the heredity-environment problem in man, particularly with respect to complex or multifactorial inheritance (von Verschuer, 1939) Unfortunately, the efforts to standardize a study procedure which fails to take into account man's genetic and biological complexity have prevented the realization of the potential value of twins

The twin study method began with Galton's recognition in 1875 of the usefulness of twins for evaluating the nature-nurture problem Galton reasoned that the magnitude of the differences between the within-pair differences of one- and two-egg twins would provide an estimate of the relative importance of heredity and environment This is still the usual method and objective of most twin studies, and while it may provide a good first estimate of heritability in a given trait, it does not fully utilize the possibilities of twins, or, in many instances, take into account other genetic and biological factors which may be important for understanding the actual nature of heredity-environment interactions

The twin study method, as originally visualized by Galton and as now generally employed, is based upon the theory that human twins are of two types· Monozygotic twins

(MZ) result from the division of a single ovum subsequent to its fertilization by a single sperm cell, and dizygotic twins (DZ) result from the separate fertilization of two different ova. While we must be prepared for the possible establishment of a third type of twinning resulting from either fertilization by different sperm cells after the division of the ovum or from fertilization of the second polar body, the occurrence of such a third type, because of lack of evidence, may be considered to have little methodological importance at present. For our present purposes we shall therefore consider that there are two types of twins single ovum twins (MZ) having identical genetic endowments, or a coefficient of genetic relationship of 1 0 or unity; and double ova twins (DZ) whom we may consider to have the same degree of genetic similarity as do ordinary full siblings, or an average coefficient of genetic relationship of 0.5. Any specific genetic or selection factor that might be associated with dizygotic twinning but not shared by single-born siblings could cause departures from this ideal in some instances, but for the moment we shall accept the comparability of dizygotic twins with single-born siblings It then follows, as postulated by Galton, that any observable difference between the two members of a monozygotic twin pair must result from environmental influences alone, while the differences between the two members of a dizygotic twin pair will result not only from environmental influences but also from differences in their genetic constitutions.

This twin study principle has been utilized most extensively for estimating the relative importance of hereditary and environmental factors in the etiology of specific disease entities In studies of this type, twins are classified according to whether one or both members of a twin pair can be considered affected.[1] If both members are affected by a given disease, the twin pair is classified as concordant, if only one is affected, the pair is classified as discordant. The heritability of the disease is then stated as a percentage value calculated by Holzinger's formula (Holzinger, 1929).

$$\frac{\%\ concordant\ (MZ) - \%\ concordant\ (DZ)}{100 - \%\ concordant\ (DZ)}$$

The classification of concordance and discordance is obviously qualitative, and no quantitative within-pair differences, or heterogeneity within the monozygotic or dizygotic twin categories, can be taken into account within this formula. It is therefore not surprising that single or major gene causation has often been inferred uncritically in the interpretation of

[1] This was in essence the method proposed by Galton, but was formalized by Siemens in 1924 as the concordance-discordance method

this type of analysis. Such influence has possibly contributed to some of the confusion which has beset evaluation of genetic evidence obtained from twin studies

Twin studies based upon the same concordance-discordance principle have been used also to estimate heritability of traits which, even for simplicity's sake, cannot be classified as qualitative. In these studies, as for example those dealing with intelligence and temperament test scores, or physical measurements, the within-pair difference values are expressed either as intra-class correlation coefficients (Holzinger, 1929), or as mean within-pair variances (Penrose, 1949, Neel and Schull, 1954). The formula[2] in its most abbreviated form becomes

$$\frac{\textit{Variance DZ} - \textit{Variance MZ}}{\textit{Variance DZ}}$$

The heritability estimate so obtained does not, of course, tell to what extent the trait is inherited, but only to what extent its variability is genetically determined If the heritability estimate obtained from either of these formulae is equal to 1.0, the interpretation must be that all of the observed variation in the trait tested is due to heredity If the estimate is 0.0, all of the variability must be due to environment, or at least it must be assumed that the majority of people in the population from which the sample was drawn are susceptible or possess the ability to react to some common environmental agents, stresses, or stimuli. As might be expected, these two extreme values are rarely met in actual experience and the problem is usually one of interpreting intermediate values Before examining the most important factors to be considered in this interpretation, we will take at their face values the concordance-discordance figures entered in these formulae, ignoring for the moment any question as to their particular or collective reliability

One of the most disconcerting problems in human genetics is the apparent lack of agreement occasionally found between the heritability estimates obtained from concordance-discordance twin studies and other types of genetic evidence These apparent discrepancies led Neel and Schull (1954) to state, with some justification, that "In its present context, the twin method has not vindicated the time spent in the collection of such data" An example commonly used to demonstrate vividly the manner of contradiction which occurs between twin heritability estimates and other types of information is that found in Mongolian idiocy In using all the twin data compiled by Gedda from the litera-

[2] Thoele and Hervey in 1952 presented a heritability formula which has been extensively used in animal genetics (Stormont, 1954)

$$h = \frac{(\textit{between pair variance}) - (\textit{within pair variance})}{(\textit{between pair variance}) + (\textit{within pair variance})}$$

ture prior to 1951 for Mongolism, Neel and Schull (1954) have calculated a heritability estimate of 0 881 This is one of the highest heritability values obtained from twin data for any severe and readily classifiable congenital defect. Other types of studies give little support to a strong hereditary predisposition in Mongolism. In fact, they indicate that heredity may play only a minor role in the etiology of the disease Maternal age and health, on the other hand, have been convincingly established as the most important of the recognized contributors to the defect, for the infant these factors are obviously environmental and not genetic in nature (Ingalls, 1947, Benda, 1950, Penrose, 1933, 1934, 1957)

At this point it would be well to consider a significant feature of the genetic relationship of twins which, though elementary, is all too frequently overlooked because of single gene orientation. Monozygotic twins are identical not only for some major gene which may be suspected of playing a role in the determination of a particular trait, but also for their whole genetic constitutions Monozygotic twins are therefore identical not only for all of the genetic factors which have a modifying influence upon the penetrance or expressivity of a major gene but also in the degree of their response to specific environmental influences. This means that monozygotic twins have identical genetic buffering systems which by homeostatic modifications of the developmental or physiological pattern will protect equally both members of the pair through the usual range of environmental variation Recognition of this complete genetic identity of monozygotic twins is of paramount importance in interpreting twin studies of multigenic characters

Lerner (1954) points out that genetically determined "developmental homeostasis must be based upon the greater ability of the heterozygote to stay within the norms of canalized development " Therefore, in a genetic system which may be heterozygous as well as multifactorial, it would be rare indeed for both members of a dizygotic twin pair to possess entirely equal susceptibility to an environmental influence and to be equally affected. Complete comparability would be correspondingly rare in siblings and collateral relatives A low familial incidence factor, if interpreted within the limits of a simple or major gene hypothesis, would appear to indicate a low inheritance factor and contradict any finding of a high monozygotic twin concordance rate, or high heritability estimate.

However, as has been pointed out (Penrose, 1953), the greater the number of genetic loci involved, the lower the familial incidence will be, even though the disease or trait depends greatly upon a genetic predisposition.

Confining the interpretation of twin evidence to a heritability estimate within the narrow conceptual limits of a simple or major gene hypothesis may therefore result in an erroneous conclusion that twin study data conflict with data from other types of genetic studies The application of a simple principle of Mendelian arithmetic to twin data, going beyond the mere calculation of a heritability estimate, demonstrates that if the difference between the concordance percentages of monozygotic and dizygotic twins is excessive, such as a ratio of 4:1, a single major gene causation is practically precluded [3]

Returning to the example of Mongolism, we find that the concordance values from which the heritability estimate of 0.881 was calculated were 88 9% for monozygotic twins and only 6.7% for dizygotic twins, a ratio of approximately 13·1 If we accept these figures at face value, the interpretation must still be that susceptibility to Mongolism is strongly inherited, but that it is probably of a polygenic nature. If any reasonable allowance is made for the reliability of these pooled twin data (see Chapter III), and consideration is given to the fact that increased maternal age, which is correlated with both dizygotic twinning and Mongolian idiocy, is the same for both members of a dizygotic twin pair but different for single-born siblings, then by a hypothesis of polygenic inheritance, the family and population incidence data of Reed (1954), Freeman (1955), and others, do not deviate as widely from the twin evidence as heretofore has been implied.[4] Vindication of twin data or of the effort expended in their collection often is less needed than a new approach to their interpretation.

Interpretation of twin data requires that consideration be given to both the nature of inheritance, whether simple or complex, and to the relative frequency of the character in the population Relatively rare multifactorial characters will yield low dizygotic twin concordance rates, as well as low familial incidence Exceedingly common characters in the population, even though multifactorial, will give high dizygotic concordances and high familial incidence figures In either case, comparison with data on the general population could lead to an erroneous conclusion that the variance due to heredity is small The best clue to the heritability of the trait would then be the

[3] Rife (1951) has presented a method for estimating multiple allelic inheritance by this principle Elementary as this interpretation is, it has been frequently ignored Book (1953) discussed the type of error in reasoning which has resulted from failure to understand this simple Mendelian principle in twin studies of schizophrenia

[4] Allen and Baroff (1955), and Allen and Kallmann (1957) discuss the relation of maternal age to Mongolism and twinning, and consider the possible etiology of Mongolism as revealed by twin data

concordance rate of the monozygotic twin pairs

The usual purpose of the concordance-discordance type of study, however, is to estimate the degree of heritability, and it might be well to ask what this estimate means in relation to the human problem To evaluate the heritability estimate, it is necessary to determine the true meaning and value of the concordant and discordant classifications The same problem that is encountered in assigning the character labels of continuous or discontinuous, quantitative or qualitative, occurs in categorizing within-pair differences as concordant or discordant The genetic diversity of dizygotic twins and the almost typical multifactorial or polygenic nature of human variation make these classifications entirely comparable. Nor can these labels be easily or objectively applied to monozygotic twins, for the within-pair differences of monozygotic twins are frequently found to have a wide and continuous range from near identity to great dissimilarity Furthermore, calculation of a heritability estimate rests on the assumption that the genetic and non-genetic components of variation have been partitioned with reasonable accuracy in comparing monozygotic and dizygotic intrapair differences. If the genetic thesis concerning the coefficient of relationship of either monozygotic or dizygotic twins is in error, or if there is a lack of comparability in the environmental influences affecting monozygotic and dizygotic twin pairs, the accuracy with which the genetic and non-genetic components of variation are partitioned is immediately open to question, as recognized by Galton. The probable frequency and significance of the exceptions to the basic assumption of the environmental comparability of monozygotic and dizygotic twins have even raised questions as to the practical value of twin data. Komai and Fukuoka (1934); Burks (1938), and Price (1950) have presented convincing evidence and argument for both the prenatal and postnatal environmental incomparability of monozygotic and dizygotic twin pairs. It should therefore be recognized that the reliability of the heritability estimate is open to serious question, and it would be well to consider even its theoretical value as a goal in twin analysis

The heritability estimate derived from twin evidence is an attempt to arrive at some measure of the extent to which heredity affects the variation of character between two individuals in a particular population at a given time. Even within these limits the estimate can not take into account the fact that the character under investigation occurs in combination with other characters with which it may be developmentally, physiologically, or mechanically correlated A heritability estimate must

further assume that the hereditary and environmental factors which may be involved in the determination of a character are entirely independent (Lush in 1948 discussed this difficulty with the heritability estimate in animal breeding) Because of the complexity of the problems with which any such estimate must deal, Hogben (1951) concluded that, "... the hope of evaluating the respective contributions of nature and nurture to variation within a genotypically heterogenous population in an environment which is not uniform is illusory in virtue of the highly complex and diverse relationship between environmental differences and the magnitude of manifest differences attributable to gene substitutions"

From a practical standpoint heritability estimates in man from whatever data should in all probability be recognized as of rather limited value The only actual use of such estimates is to test the presence of measurable hereditary variability and a simple statistical method (see Chapter VIII) which lends itself to tests of reliability with small samples is preferable to the heritability estimate While demonstration of a measurable hereditary factor is the first objective of a twin study, it should not be considered the final goal, nor does it fully utilize the possibilities of twin data.[5]

Among the important problems in human genetics are those concerned with environmental forces which modify the expression of particular hereditary predispositions Monozygotic twins are among the best subjects for study in connection with this genetic problem because of their genetic identity and common within-pair differences for the majority of measurable genetic traits. The best known method is the study of monozygotic twin pairs separated from early infancy or childhood The first detailed study of a pair of monozygotic twins raised apart was that by Muller in 1925 Later Newman, Freeman, and Holzinger (1937) reported on 19 pairs of monozygotic twins who were separated from birth or early infancy, and compared the intrapair differences of these separated twins with those of 50 pairs of monozygotic twins raised together The method employed by these authors was a direct adaptation of the concordance-discordance type of study, and Holzinger's formula for estimating heritability was adjusted

[5] Waterhouse (1953) arrived at a similar conclusion concerning concordance-discordance studies and suggested that they should be regarded merely as a forerunner to a more detailed investigation Kallmann (1954) has presented and implemented a more detailed study which he has termed the Twin Family Method This is an extension of the concordance-discordance study to a wider range of related individuals, even including step-siblings In practice this multiplies the problems of usual concordance-discordance studies, but it does have value in that it attempts to extend the interpretation of twin data

to estimate environmental influence·

$$\frac{\text{Variance of MZ apart} - \text{Variance of MZ together}}{\text{Variance of MZ apart}}$$

This method, like the heritability estimate, merely provides a test for the presence of measurable variability in a character and cannot be interpreted as reliably indicating the degree of environmental influence. The presence of an environmental influence would of course be implicit in the existence of measurable monozygotic twin intrapair differences.

Comparison of intrapair differences of monozygotic twins raised together with intrapair differences of those reared apart has great additional value, however, in providing a method for identifying the nature of the environmental influences which result in character differences Newman, Freeman, and Holzinger (1937) recognized this as a possible method for separating prenatal and postnatal environmental influences. Unfortunately, separation of pre- and postnatal environment by this method is very difficult to achieve except on the basis of a number of probably unwarranted assumptions It would have to be assumed that the within-pair variations in prenatal environment were entirely comparable in the two twin samples (together and apart), and that both samples were drawn from the same population. Because of the great difficulty in studying twin pairs raised apart, it is doubtful that either of these requirements could be adequately met. The studies of Newman, Freeman, and Holzinger exemplify the type of complication which can arise: The twin pairs raised apart came from all over the United States and had a mean age of 26 years, whereas all those raised together came from the Chicago area and had a mean age of approximately 13 years. In the presence of such an age discrepancy, it is difficult to evaluate the nature or magnitude of any environmental influence other than that of age.

A method designed to analyze specific environmental influences upon hereditary potentiality is the co-twin control method originally presented in 1929 by Gesell and Thompson By this method one member of a monozygotic twin pair is used as a check or control upon the other member under intentionally varied conditions of training or treatment. If consideration is given to the apparent comparability of the prenatal development and health status of the two members of a twin pair, this method provides a valuable experimental procedure for studying the interaction of heredity and environment. The experimental possibilities of the method are restricted by the type and degree of environmental control to which human subjects can be submitted reasonably and ethically. The intrapair differences produced by the consequently minor alterations in

environment will in most cases be small, whereas the genetic interpair variability conditioning responses to such changes in environmental stimuli may be relatively large in their effects. Broad generalizations from the controlled study of single twin pairs therefore should be avoided. The most extensive co-twin control study ever attempted was that of the Maxim Gorky Institute in Moscow (Levit, 1934) Unfortunately, the results of this study have not been presented adequately to permit satisfactory evaluation

The need as well as the possibilities for extending the twin study method are being recognized more and more Le Roy (1957) has presented a statistical model for extending a twin analysis based largely upon methods in agricultural genetics, following closely the methods described by Kempthorne (1955) By the use of such statistical methods the different components of variance can be partitioned and the full range of the genetic and environmental variables inherent in the study sample can be employed. While methods such as these hold great promise for the future, considerable work remains to be done before their full application to the analysis of quantitative attributes in man can be made (Kempthorne, 1957). For particular problems somewhat similar results can be attained with more direct procedures by taking greater advantage of the unique nature of twins For example, in a study of serum lipids in which a simple variance analysis was used, the effects of living together and sharing more similar environments upon serum lipid levels of individuals with a coefficient of genetic relationship of 1.0, 0 5, and 0.0, were compared with the effects of decreasing environmental similarity at each degree of relationship (Osborne et al , 1959) Other methods of extending twin data can be used, some of which will be discussed presently.

In studying hereditary and environmental interactions, one must keep constantly in mind the complexity of the hereditary and environmental interrelationships among different traits which result in character or phenotypic correlations While in man it is generally impossible to study separately either a simple genetic determinant or phenotypic character, it is still necessary to achieve some character delineation in a study of hereditary and environmental influences or interactions For this purpose the hereditary and environmental causes of correlation must be separated Only then will it be possible to determine whether the genetic association is brought about by selection or hybridization, and similarly, whether the environmental effects are the multiple results of a single or of different environmental forces. As long as any two characters are studied in the same individual, it

is impossible to distinguish between hereditary and environmental sources of correlation, a problem which can be overcome in animal breeding by a cross-character analysis between individuals of known relationship (Lerner, 1950). In spite of the long recognized problem of correlation of characters in twin studies (R. A. Fisher, 1925, Stocks, 1930, 1932) and the fact that the method used in animal breeding is based upon a theoretical model equivalent to the situation pertaining in monozygotic twins, this method has not been extensively applied in human twin studies. By this method the comparison of trait A of one member of a twin pair with trait B of the co-twin (Lerner, 1950) provides a test of the association between traits uncomplicated by a common internal environment (Osborne, Horowitz, and De George, 1958). An extension of this type of analysis to co-twin control studies or selected twin samples might also be worthy of consideration. For example, a cross-twin analysis in monozygotic twins discordant for a particular disease or congenital malformation could contribute important insights into the relation between primary and secondary effects.

The apparent limitations of twin analysis, as has been pointed out by many workers, may derive in large part from a failure to ask the most appropriate questions of twin data. It should be recognized that the characteristics which may cause a bias in one type of twin analysis may provide the phenotypic variation needed for another. Preoccupation with the problem of establishing the relative importance of heredity or environment rather than with that of understanding their interactions has resulted in failure to explore adequately the possibilities for extending the use of twin analysis.

CHAPTER III

Obtaining a Twin Sample

Since the time of Sir Francis Galton's presentation of the twin study method, the principal additions to the methodology have had to do with obtaining the twin sample and with diagnosis of zygosity (von Verschuer, 1939). Partly because obtaining a twin sample is logically the first problem in a twin study, and partly because certain aspects of this problem have a direct bearing upon the diagnosis of zygosity, selection of the sample will be discussed first, and diagnosis of zygosity will be taken up subsequently.

In 1927 Fisher pointed out the importance of properly obtaining a twin sample to avoid introducing an unconscious selection bias In 1930 Luxenburger proposed the "total ascertainment" of all twins in a prescribed population as the solution to this problem The reasoning behind this principle, "Luxenburger's principle of total ascertainment," is easily visualized in respect to twin studies of pathology, where bizarre cases and twin pairs concordant for some spectacular trait or disease will attract attention and thereby be more readily observed, reported in the literature, or brought to the notice of the investigator In a similar way, the twin status of an individual in any population with a pathological condition is more easily discovered if the co-twin is also affected and therefore a member of this same population The latter situation, particularly important in relation to institutionalized

subjects, led Luxenburger to the formulation of his principle.

The problem of properly "ascertaining" subjects is by no means confined to studies of twins, but is ever present and pressing in any phase or form of genetic research in man (Schull, 1954). In truth, the "ascertainment" of subjects may be relatively more simple in certain types of twin studies than in many other phases of human genetics, for example, census and birth twin data lend themselves ideally to statistical treatment adequate for some purposes. Allen (1955) presents an excellent discussion of these statistical methods and their uses, and summarizes the types of conclusions which can be drawn from general twin data, such as birth records and census reports, when the effects of different twinning frequencies, age of subjects, postnatal twin mortality, concordance rates, and the proportion of "ascertainment" are taken into account The statistical methods discussed by Allen are most useful for obtaining first or basic approximations from twin data, but by necessity they involve many untested assumptions which will require further validation for particular types of studies

The importance of obtaining twin samples free of twin pair concordance biases has resulted in the development of a method for testing the "proportion of ascertainment." By this method a bias or over-representation of concordant twin pairs will mean an excess of monozygotic twin pairs, or at least an excess of monozygotic pairs can be taken as evidence of a biased sample. The number of monozygotic twin pairs studied is compared with the number theoretically expected in that population to test for any excess of monozygotic twin pairs. The number theoretically expected is obtained by Weinberg's differential method. For this purpose a 1:1 sex ratio is usually assumed If there is a 1:1 sex ratio at birth, dizygotic pairs should occur in the proportion of 1♂♂:2♂♀:1♀♀. Since the number of unlike sex pairs equals the number of like sex dizygotic pairs, the total number of dizygotic pairs equals twice the number of unlike sex pairs The difference between twice the number of unlike sex pairs and the total number of twin pairs in the sample, therefore, is the number of monozygotic pairs to be expected

Obviously, use of this formula depends upon the availability of standard twin statistics representative of the twin population from which the sample is drawn. The twin statistics should be appropriate for the race, geographic area, and age level of the study sample to make proper allowance for differences in twinning frequency and twin mortality. However, even with further correction of the theoretical expectancies for concordance rates, estimated proportion of

"ascertainment," etc., this problem has been oversimplified in an attempt to present a standard method for general application

While this method may be entirely adequate for broad studies involving large populations, almost every study of specific or particular nature will present a unique set of problems which must be solved For example, even if all the twins afflicted with Mongolism in a population were obtained at birth, and the standard corrections applied in the "test of ascertainment," still to be considered are: first, the very real possibility of a higher than average dizygotic twin frequency because both Mongolism and dizygotic twinning are correlated highly with maternal age, while monozygotic twinning is not, and, second, the possibility, strongly suggested from empirical evidence, of a sex differential in Mongolism, for both susceptibility and mortality, which in combination could result in too few unlike sex pairs and a consequent error in estimating the expected frequency of monozygotic twins by Weinberg's formula Influences of this nature, both in kind and magnitude, may be peculiar to Mongolism, and differ significantly in other disease populations Certainly, in many of the disease entities in which we are interested, there is a strong sex incidence factor which would make "total ascertainment" of twins at birth the minimal requirement.

The importance of the general principle of "total ascertainment" of a study sample can hardly be questioned, particularly in investigations of specific or rare pathologies, but the limits of its applications, as of its value, should be recognized "Total ascertainment" performs no miraculous correction of all the biases in twin studies Of particular importance is the fact that "total ascertainment" cannot correct biases resulting from prenatal or natal influences which may differentially affect monozygotic and dizygotic intrapair differences (Price, 1950) In fact, the inclusion of all of the twins in a prescribed population in a study will tend to preserve, rather than remove, any such differences between monozygotic and dizygotic twins regardless of the age group of the sample or the nature of the study Another consideration is the possible influence which the study of all the twins in a prescribed population may have upon the ultimate application of certain types of twin evidence The purpose of any twin study is to obtain information which can be translated into values that will apply to the general population, approximately 98% of whom are not the products of multiple births. Therefore, any significant differences between twins and single-born individuals for the characters or traits under investigation will affect the value of twin study evidence in application to a single-born population

The most obvious and perhaps the best known characteristic in which twins differ significantly from single-born is in their high frequency of prematurity Guttmacher (1939) found that premature birth weight occurred five times as often in twin as in single births, and that viable twin pregnancies terminated on the average 18 days earlier than did viable single pregnancies Ross and Philpott (1953) found a prematurity rate of 65 6% among twins and evidence that prematurity was the principal apparent cause of fetal death in twins These findings by Guttmacher and by Ross and Philpott can be supported by reliable birth statistics. In Sloane Hospital for Women, New York, from 1949 to 1952, 309 viable twin births occurred, 58 0% of these infants were of premature weight as compared with 7 5% of 14,229 viable single-born (Premature birth weight was defined as viable birth weight under 2500 grams) Whatever the effects of prematurity, and there may be many (Dunham, 1955) in addition to the more spectacular such as retrolental fibroplasia and kernicterus, they would probably be the same for dizygotic twins and monozygotic twins, but because of the excessive rate of prematurity in twins, they would not be comparable for single-born.

In addition to prematurity, or factors directly attributable to it, a reduced overall survival rate in twins has long been recognized In a population with a single-born survival rate of 95 5%, Karn (1952) calculated a survival rate of 84 0% for unlike sex twins and 76 1% for like sex twins. Other studies, such as those of Bender (1952) and Ross (1953), show a reduced survival rate of similar magnitude in twins So great a difference in survival must be suspected of introducing selective differences, both phenotypic and genotypic, between viable twins and the single-born.

The relatively high frequency of congenital abnormalities in twins is of particular interest Stevenson et al (1950) in compiling statistics for 29,024 births at the Boston Lying-in Hospital, found an overall twin ratio of 1 83, but in the 673 pregnancies that resulted in babies with congenital malformations, there were 16 multiple pregnancies, a twin birth ratio of 1:42 Of the 32 babies resulting from these 16 pregnancies, 20 were malformed Sheldon (1938) and Ford (1940) found twice the expected twin frequency among children with pyloric stenosis. Abt (1924) discovered a higher susceptibility of twins to early rickets Gruenwald (1947) and others have reported frequent occurrence of cardiac abnormalities in twins. Neurological and mental abnormalities also have been found to be unusually frequent Luxenburger (1928), Rosanoff (1934), and Conrad (1935) found an excess of twins, particularly dizygotic twins, among epileptics. In 1955 Allen and Kall-

mann reported that a study of individuals committed to New York State mental institutions revealed an excess of twins in all major diagnostic categories with a different and unexplained deviation in sex ratio in some categories The evidence convincingly indicates not only that mortality among twins is greater than among single-born, but also that the mental and physical health of a disproportionate number of twins is adversely affected

A view all too often accepted, in practice if not in principle, is that once twins have come through the ordeal of being born, they are (barring obvious congenital malformation) no more the victims of their prenatal environments than are the single-born (Kallmann, 1954) Many of the abnormalities which have been found to occur with excessive frequency in twins, however, may often be delayed in their expression, or be contributory to the development of other defects at some later age An example was discovered by the present senior author while he was conducting a search for twins among new admissions to the Vanderbilt Clinic. In the course of this search 20,089 admission applications were checked (see Chapter V) and a statistically significant excess of twins was discovered among new admissions to the orthopedic clinic ($\chi^2 = 21.41$ with 1 d f, $P < .001$) The majority of the twins found in this search, and of those admitted to the orthopedic clinic, were over 20 years of age. While some of the orthopedic defects exhibited in this group may well have been to some extent apparent previously, possibly even at birth, they provide a good example of a projection well into adult life of the ill effects which may result from the early disadvantages to which twins seem frequently to be subject

It is evident from the foregoing discussion that, in studies of normal or non-pathological variation, selection of subjects on the basis of health will be necessary at any age level Because any type of selection automatically invites the introduction of bias, the principle of random sampling is frequently proposed, especially for studies of normal variation True random sampling, however, is extremely difficult if not impossible to achieve, and may be quite meaningless in human populations We do not know what a normal population is, and if we did, there would not be a single or average normal population, but a number, each differing from the others and all beyond our present ability to define Furthermore, a true random sample of twins would tend to preserve any biases resulting from a differential effect of prenatal influences upon monozygotic and dizygotic twin pairs and also from the incomparabilities which may exist between multiple- and single-born individuals.

In the choice or limitation of a problem for investigation, some selection of a study population becomes necessary, and the obtaining of suitable subjects should not be neglected for the sake of convenience, or for purposes of emphasizing the study method which may not be appropriate in every detail for the problem under investigation. It is no more possible to designate in detail a twin study procedure which will be equally applicable to all problems than it is to set forth a single statistical method for analyzing all biological data What will bias one study will not necessarily bias another, and there can be no single test or set of criteria. In human studies the necessity for a purposeful selection of subjects can rarely be avoided, consequently the only safe procedure is to determine who the subjects are and of what definable population they are representative.[1]

[1] Little, C C (1954) "I don't want to discourage the point of view of the seekers for the Holy Grail of Random Sampling That is all to the good, but why not use a deliberately prepared population?—It is easier to tell what is in a 'mince pie' when you see the components as they go into it than to try to pick them out afterwards"

CHAPTER IV

The Diagnosis of Twin Zygosity

The central problem in any twin study is the diagnosis of zygosity determining which twins are monozygotic and which dizygotic. In spite of innumerable attempts to standardize procedures, diagnosing zygosity remains the most debated problem in twin studies Galton's formulation of nature-nurture studies in twins assumed that there were two distinct and distinguishable types, but distinguishing one type from the other has always been difficult Weinberg in 1902 presented statistical evidence for the theory of two twin types, but the expectancy figure for the frequency of monozygotic and dizygotic twins derived by his formula differed sufficiently from the then accepted empirical findings to raise questions as to the validity of his method Thorndike in 1905 concluded from his data that there were not two distinctly different types of twins at all but instead a continuous range of inborn differences, for he failed to find the perfect bimodality in the curve of intrapair differences which he assumed the twin and genetic theories called for

In the twin work published prior to about 1925, it was held that monozygotic twins were invariably enclosed in a single chorion, that, conversely, all double chorionic twins were dizygotic, and consequently that the number of chorions was an absolute criterion for determining zygosity By calculation of the frequency of monozygotic twins on the basis of

fetal membranes, values were obtained that ranged from 11% to 22% with an average between 14% and 16% Weinberg, in applying the differential method, calculated a frequency of monozygotic twins which ranged from 23% to 31%, depending upon the population studied This comparatively high frequency of monozygotic twinning calculated by Weinberg's method precipitated considerable debate, and his method was not generally accepted until R A Fisher provided additional statistical evidence for these higher values in 1919 After Apert in 1923 had conclusively established that dizygotic twinning is correlated with maternal age (which had been suggested by Weinberg in 1902), this phenomenon, the difficulties encountered in sampling, genetic differences in twinning frequency, and the differential mortality in twins were invoked as explanations of the discrepancies found between the theoretically expected frequency of monozygotic twins and the observed frequency of monochorionic twins

In the meantime considerable progress was being made in describing various phenotypic differences in twins, partly out of necessity, for, although the fetal membranes were considered positive evidence of zygosity, such data were extremely difficult to obtain, they are rarely available in even the best obstetrical records In 1904 Wilder began studies of the fingerprints of twins, and by 1925, through the use of these characters and other phenotypic features, confidence in the diagnosis of zygosity was sufficient to cause Siemens (1925) to reopen the question, raised by Danforth in 1916, of the reliability of fetal membranes as diagnostic criteria. Curtius (1928) and Lassen (1931) presented further evidence which confirmed beyond question Siemens' findings. Corner (1954), in reviewing the accumulated data on the fetal membranes of twins, calculated that 38% of all monozygotic twins have separate chorions. While the presence of a single chorion may be taken as presumptive evidence of monozygosity, the presence of two chorions is now known to be useless as a diagnostic criterion In spite of this knowledge, which has been accepted in all major twin studies since 1930, the writers of obstetrical records and pathology reports still presume to make a diagnosis of dizygosity on the basis of fetal membranes It should also be noted that even the diagnosis of monozygosity can not always be relied upon from the routine description of a single chorion, for, when the membranes are damaged or fused, even a careful gross examination may be inconclusive

Acceptance of the practical limitations of fetal membranes for diagnosing zygosity left no alternative to the evaluation of phenotypic characters for this purpose However, the diagnosis of twin zygosity on the basis of

phenotypic resemblances posed a number of difficult questions which led Muller in 1925 to suggest a method for calculating the probability of concordance between dizygotic twins in certain observed traits by comparing them with their siblings, with recognition, of course, of the effect which racial or familial variation would have upon the actual value of such observed differences or similarities Muller (1925) emphasized the necessity of using non-correlated physical traits for diagnostic criteria, and of evaluating "everonic" influences (apparently meaning all influences other than genetic) that might significantly affect the twin intrapair differences relative to differences between single-born sibs Because of the possible importance of such trait correlations and "everonic" influences, Burks (1926) questioned the practical utility of Muller's method The lively discussion which ensued was entered in 1927 by Siemens who argued in favor of his own similarity method of diagnosis presented in 1924 and 1925. Apparently the basis of Muller's and Burk's discussion, and even some Mendelian principles,[1] were not fully appreciated by those interested in twin analysis, for Siemens' similarity method became the principal method of zygosity diagnosis

Siemens' method consists of simply comparing the "totality of observed resemblances of one-egg twins with those of two-egg twins . in as many traits as possible" (Siemens, 1927). For this purpose Siemens listed various traits in four levels of usefulness or reliability (a) hair color and form, eye color, skin color, and downy hair of the body, (b) such traits as freckles, acne, furrowing of the tongue, (c) form of the face, ears, hands, nails, and body build, (d) mental make-up, illnesses and abnormalities, fingerprints, and blood groups Failure to recognize the bias which the subjective use of this total array of characters would inevitably introduce into any type of twin analysis could only reflect misinterpretation of Mendelian principles The first active objections raised to Siemens' similarity method were concerned with the intangible nature of the differences or similarities used as diagnostic criteria, and the fact that the only measure of certainty was the degree of the investigator's own satisfaction in his diagnosis

In 1933, Rife presented an extension of Muller's earlier statistical

[1] To counter Muller's and Burk's concern for the genetic and environmental complexity of human variation, Siemens stated "As Mendelism has taught us the independence of individual traits in inheritance, the chance that two egg twins would be as alike as one egg twins in all the particulars of my scheme is so slight that this way, in virtually every case, one may make a diagnosis that, for practical purposes, is almost absolutely certain a mathematic calculation of this probability, such as Prof Muller has made by his method, is superfluous here" (Siemens, 1927)

method, and since this renewal of interest in calculating probability values in twin diagnosis, considerable progress has been made in refinement of the statistical procedures. With Rife's formula, it is necessary to know the genotype of the twins' parents, or at least to be able to infer their genetic constitutions from their observable phenotypes. Advances in serology and serological genetics enabled Essen-Möller (1938, 1941), Wiener and Luff (1940), and Robinow (1943) to elaborate these calculations to include the use of blood group gene frequencies when the parents of twin subjects were not available for study A number of authors, such as R. A. Fisher (1951), and Race and Sanger (1954), have since contributed to the development of these procedures The most recent and complete presentation of these statistical procedures is that of Smith and Penrose (1955), and it would appear that the purely statistical part of the method, at least for use with the blood group systems, may well have been brought to sufficient accuracy and simplicity.

Future efforts to elaborate or refine methods for diagnosing zygosity should be directed toward other than the purely statistical aspects of the problem Perhaps first to be considered is the possible extension of the diagnostic criteria beyond the blood group substances Smith and Penrose attempted such an extension of diagnostic criteria and suggested the statistical procedures required in the use of such characters, which in all probability do not depend in their expression upon relatively simple genetic determinants Similar methods have been proposed also by Sutton et al (1955)

In extending the criteria used in zygosity diagnosis, the dermatoglyphic characters, which are generally assumed to rank next to the blood group substances in reliability, are most commonly employed Since dermal patterns in twins were first studied by Wilder in 1904, various methods for their use in twin diagnosis have been devised. Unfortunately, evidence for the reliability of all of these methods has come from testing their agreement with a diagnosis made by Siemens' similarity method, which is to say that the extent to which twins with a general physical similarity also have similar dermatoglyphic patterns has been variously estimated The danger inherent in this circular test of reliability is most dramatically illustrated by the findings in conjoined twins, whose general physical resemblances and dermal characters are frequently less similar than those in twin pairs reliably judged to be dizygotic, though conjoined twins are conceded to be monozygotic. Monozygotic twins always show some differences in their dermatoglyphic characters even in the absence of other gross evidence of developmental disruption. From this

evidence it must be concluded that dermal patterns are always, and sometimes seriously, modified by environmental influences. These differences in dermatoglyphic patterns may well be correlated with differences in other phenotypic characters Traits with variable expressivity make poor diagnostic criteria, particularly those which are influenced by early developmental factors because of the apparent frequency of developmental disruptions in twins (Chapter III).

While dermatoglyphics can be an important aid in diagnosis, they are never conclusive, and neither striking similarities nor large differences constitute proof of zygosity. This is well exemplified in a table presented by Smith and Penrose (1955). In 52 monozygotic twin pairs the differences in total ridge count ranged from 0 to 40, and in 101 like sex sibling pairs from 0 to 183. Of these sibling pairs, 47 had differences from 0 to 40, as had the monozygotic twin pairs Establishment of the usefulness of dermatoglyphics as a diagnostic criterion will require a test of the correlation between the intrapair differences of these dermal characteristics and other physical traits If dermal characters tend only to approach identity in monozygotic pairs whose zygosity would not be questioned by other criteria, and differ most in dizygotic twins whose zygosity has already been clearly established by other criteria, then the considerable labor which dermatoglyphic analysis entails can hardly be justified for zygosity diagnosis save in the absence of other more useful or practical criteria.

The diagnostic characteristics actually given preference in Siemens' similarity method were hair, eye, and skin pigmentation, and body hair. While these characters may occasionally suffer modification to some degree from developmental or environmental influences, their most serious disadvantage is the extremely subjective manner of classifying intrapair differences Skin color, particularly, is subjectively classified, and its relatively high degree of modifiability makes its general usefulness highly questionable Although most investigators will justifiably accept a radical difference in eye or hair color between members of a twin pair as sufficient evidence for a diagnosis of dizygosity, the difficulty of classifying small differences makes these characters less useful for establishing monozygosity Their usefulness varies also in different racial groups (as pointed out by von Verschuer, 1939), as well as in intercorrelations between racial groups, because these characters are commonly seen as associated racial characteristics with an extreme range of both inter- and intrapopulation variance The age and sex of the subjects will obviously affect the practical usefulness of body hair as a character

for comparison, and age may affect hair pigmentation Dizygotic twins, particularly in Western European stocks, may not have discernible differences in hair color at an early age but may differ markedly at a later age, or vice versa. It is easily seen that in different populations, and even between different twin pairs in the same population, pigment and hair characteristics will differ in their diagnostic value.

The phenotypic characters of the greatest potential value for use in diagnosing twin zygosity are those which have a fairly high level of penetrance (ideally 100%) such as blood factors (barring the rare exception pointed out by Levine in 1955). In any event, a diagnostic trait must have sufficient uniformity of expression to permit acceptable objectivity and reliability in the classification or recognition of its variants. There are several such characters which vary enough in most populations to provide a potential source of additional criteria for zygosity diagnosis, as, for example, variations in ear form, teeth, iris pattern, digital hair, etc. In using such characters, however, the complex genetic nature of the majority of human variation should not be lost sight of, and even those characters which appear genetically simple or exact in their expression in one instance may be subject to both genetic and environmental modification in another instance. While radical intrapair differences in the more reliable of these traits may be employed with caution (see Appendix II) in proving dizygosity, at present there is insufficient empirical evidence of intrapair twin or sibling variances either to warrant use of any of these characters for probability calculations or to interpret minor intrapair differences as evidence of monozygosity. Obviously, differences in body measurements which characterize growth and development provide extremely tenuous diagnostic criteria It is of interest to note here that these considerations (the correlations between characters, and the genetic and environmental interactions affecting intrapair differences), which were the subject of Muller's and Burk's 1925–1926 discussion, still constitute one of the principal challenges in human genetic studies

Certain assumptions are inherent in any statistical calculation, and it would be well to examine next some of the assumptions which are made in the probability calculations employed in zygosity diagnosis. The first step in calculating the relative chance that a twin pair is monozygotic or dizygotic is to determine the probability of occurrence of the two kinds of twins in the population from which a given pair is drawn (Smith and Penrose, 1955). This basic probability is obtained by applying Weinberg's differential method to appropriate population statistics. Deviations from

theoretical values may occur in some populations. As Allen and Firschein (1957) point out, rather large errors can be introduced by disregarding the size of the effect that maternal age has on the MZ.DZ ratio. The reliability of the final probability calculation will depend in large part upon the particular population studied and upon the nature of the investigation

The second step in the statistical method for determining zygosity is to find the incidence of the differences in the diagnostic characters in the two twin types Even in blood groups, in which monozygotic twins exhibit no differences, a problem arises, for it is necessary to assume that no factors other than chance will affect the expected mathematical ratios of the blood types in viable dizygotic twin pairs If this assumption is accepted, and either the parental blood types or the gene frequencies of the population from which a twin pair is drawn are known, the incidence of differences to be expected if the pair is dizygotic can be obtained for statistical comparison with the identity which would exist if the twin pair were monozygotic. To assume that only chance would affect the ratios in the blood groups is to say that there are no important selection factors associated with the blood groups which would affect intrapair differences of dizygotic twins. With the growing body of evidence that differential fertility (Kirk et al, 1953) and survival rates in twins (Osborne and De George, 1957) are associated with blood group factors, it should be evident that the assumption of purely chance segregation ratios in dizygotic twins is open to serious question

In establishing monozygosity, calculated probability levels may, under the most favorable circumstances, approach the statistical equivalent of a positive diagnosis When a careful examination of the fetal membranes can be made and the existence of a single chorion can be established, this finding also may be taken as presumptive evidence of monozygosity Similarly, so far as is now known, a successful heteroplastic skin graft[2] is proof of monozygosity, though neither failure of the graft nor the presence of two chorions disproves monozygosity In general, and in adult studies in particular, when parents and siblings are not available to provide the most favorable conditions for probability calculations, and reliable membrane information is unavailable, some limitations in zygosity diagnosis must be accepted In reality, some limitation will almost always be present, and the only method of diagnosis which can consistently provide an absolutely dependable point of differentiation is that of proving

[2] From a practical standpoint, skin grafts will have to be limited to instances where the use of a surgical procedure can be justified

dizygosity (Osborne, 1956). This method, presented in Appendix II, has the advantage that, since the dizygotic twin category is known to be correctly diagnosed, any error can have but one direction the inclusion of like sex dizygotic twins in the monozygotic twin category

Convenient though it would be to have a single statistical procedure which could be applied to a standard battery of diagnostic characters, this is not always possible. The investigator can never be relieved of the responsibility for employing the method which is most appropriate for a particular investigation The usefulness and reliability of diagnostic characters must be separately evaluated for that investigation, with due consideration to the kind of population to be studied, whether healthy or pathological, and if the latter, to the nature of the pathology. Mongolism, as discussed above, is a case in point The age, sex, and racial composition of the population are important considerations, invariably limiting in some manner the characters used and the procedures followed, as well as their relative reliabilities. Most important of all, circular reasoning as a result of the character used in establishing zygosity must be avoided For example, with the use of a total array of characters, the only justifiable conclusion might well be that the twins who are the most similar differ the least Fisher, in analyzing the twin data of Lauterbach, as early as 1925 observed that twins more alike in one character are more alike in other characters

Part Three

The Design of the Study of Normal Morphological Variation

Chapter V

General Considerations

In any genetic study of human variation, some of the most difficult and controversial questions concern the nature of the sample to be studied Man's genetic heterogeneity, the multifactorial or polygenic nature of the greater part of his variation, and the complex environmental history behind the development of any measurable trait or attribute pose critical problems for obtaining or selecting an appropriate study sample. A population sample which does not have genetic and environmental variability will not provide measurable trait variations, but at the same time the sample must have definable genetic and environmental limits Inclusion of radically different genetic and environmental groups in the study sample will require separation of the sample into its definable elements for the analysis Since each element must be large enough for statistical validity, such a procedure may necessitate a study of impracticable size To define what would constitute radically different genetic groups is arbitrary at best, in the light of our present knowledge the limits should probably be set at the level of a major racial classification A more detailed definition of the environmental variables, however, will be required to facilitate understanding of the genetically conditioned components of variation.

The environment can be conveniently separated into several different elements, one of which may be termed

the social or economic environment, which, for valid analysis of hereditary-environmental interactions, should represent the range which is average for the genetic population studied. For practical purposes such an average can be attained most easily by centering the study upon a middle income population. Another definable element of the environment, and one of the most important, is age. As any character, however described or measured, is the result of the process of development, choice of the appropriate age level is the most critical single factor in the selection of subjects for study. Obviously, for a study of senescent changes, subjects of advanced age will be required, while children will be needed for a study of growth rates or patterns of development. As both genetic and environmental factors affect the process of growth and aging, as does the environmental component, age itself, the interpretation of studies of subjects at the maxima of these processes is extremely difficult except in terms of the processes themselves If the purpose is not specifically to study character variation in growth or senescence, the subjects should be past the age of major growth and development but should not have reached the age of rapid decline. Similarly, unless the investigation is concerned with a particular pathology, subjects exhibiting medically definable pathologies, or a history of serious disease, whether genetically or environmentally determined, should be excluded from the study population. Such a selection of subjects has additional value in a twin study in that it will tend to reduce two of the principal biases to which twin data are susceptible (see Chapter III).

All twin studies so far carried out with non-pathological or non-institutionalized subjects have included children of school age. Lauterbach (1925) studied 212 pairs of school age twins, while Dahlberg (1926) studied 243 pairs of twins utilizing subjects from 3 to 30 years of age, only 47 of which were over 18 years old. Stocks (1932, 1933) published extensive data on more than 250 pairs of twins ranging in age from 3 to 15 years In 1927 von Verschuer published a study of 104 pairs of non-institutionalized twins from 3 months to 68 years of age In a later report (1952) von Verschuer presented data on 5,000 unspecified pairs of twins, presumably of all age levels, including institutionalized as well as non-institutionalized subjects. In the Chicago study by Newman, Freeman, and Holzinger (1937), the mean age of the subjects was 13 years. Vogel and Wendt (1956) reported a study of 170 pairs of twins ranging from 6 to over 20 years of age. In the Michigan study (Clark, 1956) of 81 twin pairs aged 12 to 20 years, the median age was 16 years, well within the period

of rapid growth and physiological change

The young average age typical of twin study subjects is in part the consequence of the greater difficulty in obtaining adult twin pairs Children can be secured as subjects for study through school or parental control and cooperation, but in a society which allows the individual choice of occupation, freedom of geographical movement, and the right to refuse to be studied, it is far more difficult to obtain adult pairs The ramifications of this difficulty may affect the conclusions drawn from twin data The greater mobility and freedom of males result in fewer intact adult male twin pairs than female available for study. Furthermore, if either heredity or environment plays any role in conditioning the temperament, personality, or ability factors that affect choice of occupation, way of life, interests, and family dependency, a disproportionate loss of available adult pairs by both sex and zygosity type is to be expected (Lehtovaara, 1938) As the influences which affect the proportions of different twin categories available for study are normal, any attempt to select for a theoretical proportion of twin types will invariably bias the sample An intentional selection by either sex or zygosity will mean that certain pairs will not be at the norm for their sex or zygosity, or will not be drawn from the same or even comparable populations Because the proportion of twin pairs by sex and zygosity which can be expected in an adult population in good health is not known, such intentional selection of the study sample may result in biases beyond any possibility of evaluation Therefore, to study a non-institutionalized adult twin population in good health, it is necessary to take all qualified twin pairs as they come, irrespective of sex and zygosity, and to obtain the information necessary for an evaluation of the sample

Chapter VI

The Source and an Evaluation of the Study Sample

In the present study, voluntary subjects from a middle income population were taken as they came, provided that both members of the twin pair were available for study, in good health, over 18 years of age, and members of the Caucasian race. To obtain a representative sample of an adult population, various lists that would include twins were used. An impersonal search of records or membership lists of universities, YMCA, YWCA, and other organizations was made, and posters were placed on bulletin boards requesting the names and addresses of twins. Friends and colleagues of the authors, and twins who responded for study were asked to assist. The twins proved to be one of the best sources of additional potential subjects From these various sources the names and addresses of 340 pairs of twins were obtained Applications for admission to the Vanderbilt Clinic of the Columbia-Presbyterian Medical Center in New York were studied also Most new patients admitted to a large hospital clinic are essentially normal individuals who are seeking medical attention for minor complaints, and they represent diverse social and economic backgrounds A question whether the applicant was a twin or had a twin in the immediate family was stamped on all clinic admission blanks The clinic registrars assisted in seeing that this question was answered, and a check was made each night after the records had been sent to the hospital record room In

a 14-month period, 20,089 applicants were questioned, and as a result 354 twin pairs were found, bringing our total register to 694 pairs. In compiling this register of names and addresses, as much information as possible about each pair of twins was secured It was then possible to select by age, race, and stated health status those who appeared to be qualified for study

A letter describing the twin study was sent to each of 382 twin pairs considered qualified, and a careful record was kept of all correspondence Of this number, 128 pairs were excluded because they could not be found or because one or both members of the pair were not available for study. Every effort was made to get as many of the remaining 254 pairs as possible to come in for study. Appointments were made at the twins' convenience for evenings, week-ends, and holidays (See Appendix I-A for an outline of the study procedure.) On occasion it was necessary to make as many as seven or eight appointments for a twin pair; some contacts were continued nearly three years before the pair was finally examined Of the 254 pairs potentially qualified and available, 131 pairs, or 51.6%, were studied

Reliance upon volunteer participation creates a possibility of introducing a bias which would affect intrapair variances If twins participated in the study because their similarities aroused their interest in their twin status, the magnitude of intrapair variances would probably be reduced artificially To evaluate this effect, an attempt was made to elicit testable information from all of the 254 pairs considered qualified for study If the twin pair either failed to respond to the original contact letter or did not request an appointment for study, a second letter and a questionnaire were sent If the pair still failed to respond, a third letter and a second questionnaire were mailed If the third letter failed, an effort was made to reach the pair by visit or by phone Eventually completed questionnaires were obtained from 76 additional pairs of twins who did not otherwise participate in the study. Consequently there were only 47 pairs, or 18 5% of the original 254 twin pairs, about whom no specific information was available. To interpret the questionnaire data, the essential questionnaire information was obtained from all twin pairs when they came in for study The information sought was whether they considered themselves, or were considered, to be identical or fraternal twins, how tall they thought they were, and how much they thought they weighed The questionnaires also elicited social and educational information, which was similarly obtained when the pairs were studied, to provide data for an evaluation of the study sample in respect to these factors.

The twins' own estimates of their zygosity, height, and weight were used to calculate mean intrapair differences in height and weight, and similar calculations were made on the basis of measurements taken at the time of study. While individuals occasionally misjudged their height and weight by a fair margin, the mean intrapair differences calculated from the estimates and actual values showed remarkable agreement for both those twins who considered themselves to be identical and those who considered themselves to be fraternal. The greatest discrepancy between means calculated from estimated and actual values occurred in the females considering themselves to be fraternal. Here the means differed by .26 inches in height, and by 1.85 pounds in weight. The mean intrapair values calculated from the estimates of height and weight would appear to be sufficiently reliable for comparison of the studied and unstudied twin pairs. When the questionnaire twins' and the studied twins' own estimates of height and weight were compared, and both groups were classified in accordance with their own zygosity diagnosis, the mean intrapair height and weight differences of the two groups were found to be in almost perfect agreement. Therefore, with respect to height and weight as indicators of physical similarity between the two members of a twin pair, there was no evidence that twin pairs who participated in the study looked more alike than those in the original group of 254 pairs who did not participate.

To be eligible for participation, both members of any given twin pair had to be in good general health. To verify the health status of each subject a careful health history was taken, and a complete medical examination was made by a staff physician at the time of study (Appendix I-A). To assure comparability of data, medical history and examination forms were used to permit the recording of negative as well as positive findings. Routine laboratory tests were made: erythrocyte sedimentation rate, complete blood count, urinalysis, and chest x-rays. On the basis of these examinations, one or both members of 16 of the 131 twin pairs studied were found to have sufficient impairment of health to be excluded from the analysis (Appendix I-B).

A second requirement was that the subjects be over 18 years of age. At the time of study it was discovered that the ages of three pairs of twins (Appendix I-B) had been misrepresented, as these three pairs of twins were under 18 years of age, they were dropped from the study sample.

To evaluate the twin sample and at the same time establish the comparability of the different twin cate-

gories, it was necessary first to classify the pairs in accordance with their zygosity diagnoses. The method employed in diagnosing zygosity (Appendix II) was based on proving dizygosity by extensive serological tests and selected morphological characters. By this method the only zygosity category which even in theory could be conclusively proved was reliably established, the only possible error in diagnosis would be the inclusion of extremely similar dizygotic twin pairs in the monozygotic category. The advantage of this method is that it provides a known direction of any error in diagnosis, and therefore a known direction of effect upon conclusions: an underestimation of the importance of the genetic component.

The mean ages of each sex and zygosity category, presented in Table 1, fall around 24 to 27 years, safely within the most stable morphological and physiological age period. An objective evaluation of social background, or even occupation, becomes extremely difficult, and the study sample is probably best described as representing a low middle to upper middle income group. This can be demonstrated by educational level, so far as it reflects these complex social or economic factors. In the study group 5 34% of the subjects reported only grade school education; 7 25% went to, but did not complete, high school; and

Table 1.
Mean ages of twins studied

		n	*Mean*	*S D*	*S E*
Monozygotic					
Male	♂♂	25	25 8	±8 84	1 77
Female	♀♀	34	26 1	±7 94	1 36
Dizygotic					
Male	♂♂	10	23 6	±5 05	1 60
Female	♀♀	27	27 1	±9 82	1 89
Unlike sex	♂♀	16	26 7	±8 30	2 07

16.03% completed high school but took no further training. Those taking training beyond high school were as follows: 13 36% attended trade school, night school, or occasional college courses, 25 57% were in college at the time they were studied, 23 28% had completed college. The remaining 9 16% had taken at least some training beyond college level. In respect to educational, financial, and occupational factors, there is no indication that the monozygotic, like sex dizygotic, or unlike sex twin pairs were drawn from different populations.

From Table 1 it is apparent that in each sex and zygosity category the proportions deviated markedly from a 1:1 sex ratio or a 1:1:1 ratio of monozygotic to like sex dizygotic to unlike sex twin pairs. This deviation was in accordance with that anticipated in volunteer adult pairs from a normal, healthy population. Females outnumbered males, and monozygotic pairs outnumbered like sex

dizygotic pairs, and like sex dizygotic pairs outnumbered unlike sex pairs

Table 2 Concordance—discordance in educational level

		n	*Concordant*	*Discordant*	*% Discordant*
Monozygotic					
Male	♂♂	30	28	2	6.67
Female	♀♀	40	37	3	7.50
Total		70	65	5	7.14
Dizygotic					
Male	♂♂	10	7	3	30.00
Female	♀♀	33	26	7	21.21
Total		43	33	10	23.26
Unlike sex	♂♀	18	10	8	44.44

Table 2 indicates that monozygotic twins were more similar than dizygotic twins, presumably in the complex of temperament, interest, ability, and motivational forces which are associated with educational attainment Similarities of the same type were necessary for both members of a twin pair to be interested and willing to participate in the present study While the small percentage of dizygotic pairs concordant in educational status indicates that dizygotic twins of diverse interest were studied, it is possible that those studied were more similar psychologically than the average for dizygotic twins This possible bias, taken together with the concordance differences of monozygotic and dizygotic twins for educational level, would be of major concern if psychological or intelligence testing were to be done with a twin sample of this nature For a study of morphological or physiological variation, however, a much stronger correlation between psychological attributes and morphology and physiology than has yet been demonstrated would have to be assumed if this selective factor were to be considered a source of serious bias.

The excess of female twin pairs in Tables 1 and 2 may in part represent the difference between the sexes in freedom of choice and geographical movement The greater reluctance of males to be studied even when both members of a pair are available must play some part in the smaller number of male pairs. This has long been a well-known problem ". it is found more difficult to get measurements on two adult brothers, than on two sisters" (Pearson, 1903). There is no question that cultural and psychological forces have affected the composition of this study sample, and the direction of the departures from equal numbers of males and females, or from a theoretical ratio of zygosity types, is in accordance with what might be expected from these influences. So far as it has been possible to determine, there is no reason to suspect a serious effect upon the physical resemblances or differences

of the twin pairs studied. There are other factors of a biological nature, however, which can affect the composition of a study sample, and thereby influence data on physical attributes and the interpretation of the data. These factors will be given consideration for their possible effect on conclusions based on these and similar twin data

Chapter VII

The Frequency of Twin Pairs in Relation to Sex and Zygosity

The frequency of twins and the proportions of pairs by sex and by zygosity depend upon the age level of the population. In a review of the accumulated evidence, Greulich (1934) concluded that by adulthood the number of twins in the general population would be approximately 50% of the twin birth incidence These were also the conclusions of Eckert (1928) Westergaard (1891–92), using English insurance company statistics, found that as early as age five male twins had been reduced by one-half, and females by one-third. In a study of 75,013 California school children, Wilson and Jones (1931) discovered a 38 2% over-all loss of twin children, and like Westergaard, a disproportionate loss of males Infant mortality and the excessively high frequency of congenital malformations or other disease states in twins contribute heavily to these findings, which have particular importance in a study of adult twins in good health.

Table 3 presents the number of twin pairs according to sex in the principal studies of essentially healthy subjects in which no apparent selection was made for either sex or zygosity. To demonstrate the tendency of the proportion of male to female like sex pairs and unlike sex pairs to decrease with increasing age, the different studies are listed, as nearly as possible, in accordance with the age level of the sample. Chi-square values have been calculated and significant departures from a secondary (at

Table 3.
Sex composition of twin study samples

		♂♂	♀♀	χ^2	♂♂+♀♀	♂♀	*Total*
Lauterbach (1925)	n	71	78	33	149	63	212
	%	47 7	52 3		70 3	29 7	
Wilson & Jones (1931)	n	260	364	17 33*	624	318	942
	%	41 7	58 3		66 2	33 8	
Merriman (1924)	n	49	82	8 31*	131	70	201
	%	37 4	62 6		65 2	34 8	
Dahlberg (1926)	n	84	107	2 77	191	52	243
	%	44 0	56 0		78 6	21 4	
Waterhouse (1950)	n	419	681	62 40*	1100	315	1415
	%	38 1	61 9		77 7	22 3	
Present study	n	35	61	7 04*	96	16	112
	%	36 5	63 5		85 7	14 3	
Total	n	918	1373	98 18*	2291	834	3125

*χ^2 significant at < 01

birth) sex ratio of 1:1 are indicated

Table 4 presents similar data from studies in which actual diagnoses of zygosity were made Interestingly, the data of Table 4 imply that the loss of male-male pairs may not be due to a monozygotic twin loss, as has been suggested (Yerushalmy and Sheerar, 1940), but may be due to a deficiency of dizygotic male-male pairs available for study. The obvious deficiency of unlike sex pairs seen in Table 3 adds credibility to this finding.

To investigate the possible effect of selection which might influence dizygotic twin intrapair differences or otherwise affect the interpretation of twin data, sibling data were obtained. At the time of study every twin pair was questioned about their single-born siblings, and every effort was made to carry out a parallel study of the siblings and parents It soon became apparent that the siblings lacked the incentive essential for voluntary participation An extremely poor sibling response resulted, and there was evidence that a large proportion of those who cooperated did so to get the benefit of a medical check-up because of some health problem In all, only 29 siblings were studied, but even this limited number was of some value It was discovered that only 30 0% of the dizy-

Table 4.
Sex and zygosity composition of twin samples

	Dizygotic			Monozygotic			
	♂♂	♀♀	x^2	♂♂	♀♀	x^2	Total
Newman (1928)	24	28	308	25	18	1 139	95
%	46 15	53 85		58 14	41 86		
Dahlberg (1926)	38	57	3 800	46	50	167	191
%	40 00	60 00		47 92	52 08		
Clark (1956)	14	23	2 189	23	21	091	81
%	37 84	62 16		52 27	47 73		
Present study	10	27	6 429*	25	34	803	96
%	27 03	72 97		42 37	57 63		
Total	86	135	12 726*	119	123	2 200	463
%	38 91	61 09		49 17	50 83		

* x^2 significant at $<0 025$

gotic twins were discordant for their ABO blood groups, in comparison with 52 5% of the sibling pairs (Osborne and De George, 1957)

To investigate the possibility of selective survival in dizygotic twins in relation to the ABO blood groups, additional twin subjects were obtained from the Fetal Life Study of the Columbia-Presbyterian Medical Center In this juvenile twin sample evidence of an ABO selection factor was found to be much stronger than in the adult group Other characteristics of the juvenile sample, principally those relating to health status, suggested complex relationships of sex, zygosity, and survival which could have important implications for the interpretation of twin data. All Sloane Hospital records of twin deliveries classified as viable (weight of 1000 grams or more) for the period 1945 to 1954 inclusive were studied The sex and survival data from these records are presented in Table 5, classified as to whether the mother was a private or a ward patient, and as to whether she was white or Negro. One or both of 23 of the 395 viable twin pairs died before discharge from the hospital With this small number of neonatal deaths, no statistical test is possible, and only the percentage of loss is indicated. The smaller number of male-male pairs in the ward groups and the smaller number of unlike sex pairs are suggestive of the data given in Table 3, where it was noted that as the ratio of male-male pairs decreased, so did the ratio of unlike sex pairs.

Table 5. Viable twin pairs born in Sloane Hospital 1945 to 1954 inclusive, by race and by hospital service*

		Total					Neonatal deaths		
		♂♂	♀♀	♂♂+♀♀	♂♀	*Total*	*One twin*	*Both twins*	*% Loss*
Private white†	n	54	35	89	45	134	3	1	2 99
	%	60 67	39 33	66 42	33 58				
Ward white	n	50	61	111	42	153	9	2	7 19
	%	45 05	54 95	72 55	27 45				
Total white	n	104	96	200	87	287	12	3	5 23
	%	52 00	48 00	69 69	30 31				
Ward Negro	n	35	40	75	33	108	5	3	7 41
	%	46 67	53 33	69 44	30 56				
Total	n	139	136	275	120	395	17	6	5 82
	%	50 55	49 45	69 62	30 38				

* Weight 1000 gms and over
† There were no private patient Negro twins born during this period

A comparison of male and female pairs in the private and ward white categories (Table 5) gives a chi-square of 4 23, with 1 d f, P = .04 While all deviations from the expected numbers are small, with only borderline significance in the comparison of private and ward white categories, there are two features of interest The first is that the expected reduction in the number of like sex pairs and consequent increase in the ratio of unlike sex pairs due to a simple loss of male-male pairs did not occur. Instead, the ratio of unlike sex pairs decreased as the proportion of male-male pairs decreased, again indicating that the male loss may be a loss of dizygotic males, whether of like or unlike sex pairs

The second feature is that the sex ratio at birth is more strongly related to some factor inherent in private and ward status than it is to race The sex ratios of the ward white and ward Negro viable twins are very similar to each other but differ from that seen in the private patient population The effect of socio-economic status upon the sex ratios at birth has been previously noted the higher the socio-economic status, the higher the male incidence (Bernstein, 1948). A complex relationship between economic status and the incidence of twins has been reported also by

Lilienfeld and Pasamanick (1955), they found that in Baltimore the ratio of unlike to like sex twins decreased with rising socio-economic level. Applying the Weinberg differential method, they interpreted their data as providing evidence for a higher prenatal survival of monozygotic twins in the higher socioeconomic groups On the other hand, if in the data given by Lilienfeld and Pasamanick survival is in reality more closely related to sex than zygosity, a higher survival rate of male-male pairs would, as previously pointed out, affect the ratio of unlike sex pairs The use of Weinberg's differential method might then incorrectly indicate a higher frequency of monozygotic twins While the private group in the present data in part represented a higher socio-economic group, the ward group did not necessarily equate with the lower socioeconomic categories of the Baltimore study. Perhaps of equal importance is the fact that medical care for private and ward patients differed relatively little in the present data, whereas in the Baltimore data it may have differed widely. In that case, the factors which influenced sex and zygosity in the two series would be quite different, and the chief point of agreement between the two sets of data would be that both demonstrate the modifiability of the ratios of twin pairs.

With the suggestion that some prenatal factors differently affected the secondary sex ratios in the private and ward populations, we obtained abortion data for the period 1950 to 1954 inclusive. After exclusion of all *therapeutic abortions*,[1] cases where pregnancy was not conclusively established, or where there was an indication of intentional interference with the pregnancies, there were 1845 Negro and white abortions. These included: early abortions (less than 15 weeks), late abortions (15 to 19 weeks), and previables (20 to 27 weeks, weight under 1000 grams) Table 6 presents statistics for the 349 abortions of single fetuses in which sex was recorded. In recognition of the problem to be encountered in sex determination (Tietze, 1948), great care was taken to assure that a careful sex diagnosis had been made, and sex determination was accepted only for fetuses over an estimated age of 12 weeks. In the private service the excess of male abortions is not quite as marked as in the ward; this may reflect a larger number of male viables (as could be inferred from the sex ratio in the twin data of Table 5) rather than any difference in the primary sex ratio.

[1] Therapeutic abortions were excluded because the purpose of the present investigation was to establish the sex ratio in spontaneous abortions, rather than the primary sex ratio

Table 6

Sex distribution in single abortions, by hospital service and race

		Early		*Late*		*Previable*		*Total*	
		♂	♀	♂	♀	♂	♀	♂	♀
Private*	n	15	1	28	5	23	29	66	35
	%	93.7	6.3	84 8	15 2	44 2	55 8	65 3	34 7
Ward white	n	16	1	28	5	29	18	73	24
	%	94 1	5 9	84 8	15 2	61 7	38 3	75 3	24 7
Ward Negro	n	14	2	45	13	42	34	101	49
	%	87 5	12 5	77 6	22 4	55 3	44 7	67 3	32 7

* One single-born Negro female excluded

In only 575 of the 1845 spontaneous abortion records could the number of aborted fetuses be established [2] Of these 575 abortions 20 were recorded as twins (Table 7); they are scattered irregularly throughout the various categories and the data yield no additional information about the sex ratios observed in the viable twins While these abortion data do not reveal an excess of male twin abortions, they obviously do not give a complete record of either sex or number of twin conceptions in the 1845 abortion records examined. Furthermore the earlier the abortion, the less complete the information as to sex and number of fetuses; an early loss of males or of twins would not be detectable.

Certain comparative calculations can be made, however, which may be of interest as the data from these records are in all probability as accurate and complete as any records presently available The twin incidence in the 575 abortions suitable for calculation of incidence figures was 1 28 2 Among the private patients it was 1·22, and in the ward population it was 1.31 1 In the ward population the ratio among whites was 1 77, and among Negroes 1 22, but the numbers are so small that they have little reliability In the same hospital during the same five year period, the numbers of viable twins and of all viable births was 240 18,357, or an incidence of 1 76 5. The hospital statistics for viable births do not permit a separation on the basis of race, and a viable twin incidence only for private and ward patients can be calculated This is

[2] Only those cases were included in which intact fetus or fetuses were observed and there was no evidence of any possible loss of products of conception prior to the patients' admission

Table 7. Sex distribution in twin abortions, by hospital service and race

		♂♂	♀♀	♂♀	Sex unknown*
Private†	n	2	1	0	4
Ward white	n	0	1	0	1
Ward Negro	n	3	4	3	1
Total	n	5	6	3	6

* Undifferentiated for sex or sex not specified (sex diagnosis not accepted for fetuses under 13 weeks' gestation)
† One Negro female not included

Table 8. Sex of individuals in juvenile twin birth series

	♂♂	♀♀	♂♀	Sex unknown	Total
Non surviving*	15†	6	0	4‡	25
Surviving	49	48	44	–	141
Total pairs	32	27	22	2	83

* Includes abortions, stillbirths, and neonatal deaths
† Includes 5 pairs of twins
‡ Includes 2 pairs of twins

found to be 1 94 3 for private, and 1 68 9 for ward patients (both white and Negro). If the abortion and viable birth data are combined to obtain an estimate of the incidence in all pregnancies represented here, the twin incidence among private patients was 1 88.1 and among ward patients 1 66 2 These abortion data provide further evidence of a higher incidence of twin conceptions than is indicated by birth records, as was hypothesized earlier in a study of the possible early fetal loss of twins in relation to the ABO blood groups (Osborne and De George, 1957)

If comparable information for twin and single-born abortions is used, the twin abortion rate is found to be two and one-half times that of singletons The neonatal mortality of twin individuals is 3 67%, affecting 5 82% of all viable twin pairs, the neonatal mortality for the single-born during the same period is 2.30% While the neonatal mortality of twins is greater than for the single-born, both percentages, as well as their ratios, are lower than usually reported (see Chapter III). These lower mortalities reflect the better than average obstetrical and pediatric care, which resulted in the survival of a certain percentage of the less favored infants who would otherwise have been lost by the end of the neonatal period.

A possible consequence of reducing prenatal loss and neonatal mortality can be seen in our juvenile twin series, a special sample of the larger Sloane Hospital twin population. This juvenile twin series was obtained from the Fetal Life Study carried out in the Departments of Obstetrics and Pediatrics of the Columbia-Presbyterian Medical Center (McIntosh et al., 1954). All expectant mothers admitted to Sloane Antepartum Clinic from 1946 to 1952 inclusive, with a duration of pregnancy of four months

or less on their first visit, were included. After exclusion of the women transferred or discharged from the clinic for various reasons, there were 5964 pregnancies, of which 83 were twin pregnancies. In Table 8 the data on survival of these 83 twin pregnancies are presented. An excess of males among the total twin pregnancies, 32 ♂♂ to 27 ♀♀ pairs, was reduced by prenatal and neonatal deaths to an equal proportion of males and females surviving the neonatal period. The surviving infants were carefully followed in the pediatric clinic until one year of age.

In 1955, when these twin pairs were four or more years of age, all those available for study were brought into the pediatric clinic for medical check-up, blood tests, and zygosity diagnosis. The health status of 68 surviving twin pairs was evaluated. A count was made of the twins definitely presenting sufficient impairment of health to preclude eligibility for a study comparable with that of the adult series (Osborne and De George, 1957). The result of this evaluation is given in Table 9. The initial excess of males had been reduced in the neonatal period, and following this there was an excessive elimination of unlike sex pairs because of impaired health. (The male was affected in three pairs, the female in three pairs and both members in seven pairs.) Since the loss of male-male pairs occurred earlier than did that of the unlike sex, and since it was more frequently due to death, it would appear to reflect a more serious disadvantage for male pairs, though the loss of unlike sex pairs was more frequent on the basis of postnatal health. The actual proportion of the male loss is of course not known, for, as has been indicated, early abortion data can not be complete. From the data from this juvenile series, however, the following loss of twin pairs as a result of death or ill health can be calculated: male-male 31.2%, female-female 26.0%, unlike sex 59.1%. The greater loss of male than female twin pairs is in accordance with previous observations, and the high loss of unlike sex pairs is consistent with the data given in Table 3.

Table 9. Health status of surviving juvenile series twin pairs

	♂♂	♀♀	♂♀	*Total*
Healthy	20	20	9	49
Health impaired	3	3	13	19
Total	23	23	22	68

In testing for relationships among maternal age, time of abortion, and sex, no significant correlations were found. Similarly, when the health status of the twin subjects in either the adult or juvenile series is tested against maternal age and parity, no apparent relationship is discovered. Surprisingly, negative results were

found also in an analysis of birth weights of live-born twins on the bases of either actual birth weight or intrapair birth weight differences. It should be emphasized, however, that these findings would not necessarily be comparable with those from similar studies of the single-born. In twins, birth weight does not have the same relation to maturation that it has in the single-born (Folsome, 1956). Intrapair differences in birth weight of monozygotic twins have been compared with intrapair differences in dermatoglyphics and tooth dimensions. These two sets of characters were used to provide a measure of developmental differences, since dermatoglyphics are formed early in prenatal development while the dimensions of the permanent teeth are established later. No significant correlations were found in either the healthy twins or those with impaired health.

From the data presented here, certain general conclusions can be drawn which have importance for the interpretation of twin data. Adult twin pairs, particularly those in good health, are the surviving representatives of a much larger initial twin population than even the birth records indicate. The twin data from other studies (Tables 3 and 4) and the data from our hospital series (Tables 5-9) raise a question as to whether it can be assumed that only monozygotic twins suffer from the hazards of multiple conception. If the actual twin conception rate, including that of dizygotic twins, is as high as these data imply, and if twin survival is related to both sex and genetic constitution, the comparability of dizygotic twins with single-born siblings, and probability calculations based on simple segregation ratios must be re-evaluated. For such a re-evaluation, application of Weinberg's differential method to heterogeneous data will not be sufficient; data from actual observation are essential.

The above conclusions are clearly in accord with those set forth in Part Two "An Evaluation of the Twin Study Method." There is no simple formula for the interpretation of twin evidence, nor for the evaluation of a twin sample. The numbers of pairs can deviate markedly in both sex and zygosity from theoretical proportions, as a result of many influences. Since the general improvement in obstetrical and early pediatric care will undoubtedly result in greater survival of the developmentally less favored, medical evaluation of a study sample will become increasingly important. Certainly for the selection of a healthy twin population there is no substitute for a thorough medical examination *of all study subjects. Each study population* must be described and evaluated.

Chapter VIII

The Method of Analysis

We have discussed the importance of studying complex or polygenic inheritance in man, and the use of twin study methods for this purpose The adult twin sample obtained for the present study has been described and evaluated Before presenting the methods of analysis, we shall consider some of the characteristics of morphological variability to be analyzed

Because of the limitations of our present knowledge, visible and measurable characters present certain distinct advantages for the study of complex or polygenic inheritance in man Morphological measurements can be made with relative precision, the range of their variability is great, and considerable evidence of the presence of both hereditary and environmental components of variability has been accumulated. Evidence from racial studies has established the range of variation for a large number of morphological measurements, and has provided clues as to which measurements are relatively more stable and which more susceptible to environmental modification (Boas, 1912, 1928, Shapiro and Hulse, 1939, Trevor, 1953) Other types of studies have shown that there is a wide range of familial correlations for different measurements (Pearson, 1903; Davenport, 1925, Howells, 1949) Still others have shown interrelationships between certain measurements forming relatively independent measure-

ment groups, indicating independent growth or genetic factors affecting different body complexes (McCloy, 1940; Howells, 1951, 1953)

A reliable measurement is prerequisite for a genetic study of polygenic variability, but it alone will not necessarily define a polygenic character A measurement may be taken only because a caliper can be conveniently and accurately applied to a set of morphological points, or because a mechanical device or method can be devised for measuring some definable variable, such as stature, blood pressure, or the amount of lipid fraction in the blood serum Only after a hereditary component of measured variation has been demonstrated, and some idea of this measurement's hereditary and environmental interrelationship with other measurements or traits has been established, can a polygenic character be delineated. The first problem in the study of polygenic inheritance, therefore, is to evaluate different measurements to determine whether or not they provide measurable hereditary or environmental variability. Our purpose here will be to examine common and readily obtainable morphological measurements for their value as indicators of inherited or environmental variation, and to determine, so far as possible, the interrelationships between some of the more critical of these variables

To take the greatest advantage of the unique nature of twins, the statistical methods employed should require the fewest possible assumptions concerning the purely biological aspects of the data. For this reason a simple variance analysis will be used for comparing the intrapair differences of the different twin categories This method facilitates comparison of the observed intrapair twin difference with measurement error and with the equivalent of random pairings of unrelated individuals, and it permits testing for sex differences.

The mean of the differences between the two members of twin pairs is expressed as a mean variance This mean intrapair variance is $(\Sigma x^2/2n)$, where n is the number of twin pairs, and x the difference between the two members of a twin pair for a given measurement In reality, this is the same as a measure of the mean difference, i e., the mean of the variance between the members of the twin pairs. By using mean variances, the significance of the differences between mean differences in the various comparisons can be obtained by the F test, which provides the best test of significance in data of this type For the F test the larger variance is divided by the smaller variance, and the "Table of the F distribution" is used to obtain the probability level of the ratio. The table of the F distribution used in our study was that

of Pearson and Hartley (1956). The observed ratio was taken to the nearest percentage point, and greater (>) and lesser (<) signs applied accordingly. The probability levels given are .25, .10, .05, .025, .01, .005, and .001.

The mean measurement error variance (ME) has been calculated in a manner comparable to that of mean intrapair variances. In this instance, x equals the difference between the first and second measurement taken on the same individual, and n equals the number of individuals measured twice. To compare the mean dizygotic intrapair variance with that of the unrelated pairs, mean interpair variances (IP) have been calculated from the averages of the values for the two members of each dizygotic twin pair. Only dizygotic twin pairs have been used, as it was felt that they would provide a more conservative and a more meaningful comparison with the dizygotic intrapair variances. The mean variances[1] obtained from the pair averages were multiplied by two to make them comparable with the intrapair dizygotic variances, since the latter are based upon means of pairs of individuals.

In monozygotic twins the difference between the two members of a twin pair is the result of measurement error plus between-individual differences, and it would therefore be expected always to provide a larger variance than measurement error. Consequently, in obtaining the level of significance for the difference between the mean measurement error (ME) and the mean monozygotic intrapair variance (MZ), a one-tail test is appropriate. As dizygotic twin differences are the result of environmental differences plus a difference in one-half of their total heredity, the mean dizygotic intrapair variance (DZ) can be expected always to exceed those of monozygotic twins, therefore a one-tail test is used. Since the mean interpair variances (IP) should always exceed the dizygotic intrapair variances, again a one-tail test is appropriate. Since in the sex comparisons of male monozygotic to female monozygotic, and male dizygotic to female dizygotic twin pairs there is no reason to assume one sex will consistently provide a larger variance than the other, a two-tail test is required. In comparing like sex dizygotic twins with unlike sex pairs (MF or ♀ ♂), the intrapair variances of the latter are the result not only of a difference in one-half of their total genetic constitutions, but also of a difference in sex, therefore, the unlike sex variance is expected to be always larger, and a one-tail test of significance is used.

[1] $s^2 = [\Sigma x^2 - (\Sigma x)^2/n\}/n - 1$, where s^2 equals mean variance of control sample, x equals the average of a given measurement of the two members of a twin pair, and n equals the number of twin pairs

In this analysis, a statistically significant difference between mean measurement error variance (ME) and mean monozygotic intrapair variance (MZ) indicates that the measurement technique is sufficiently accurate to determine the effect of extragenic influence in monozygotic twin pairs. If the ratio of these variances is not significant, either an inaccurate measurement or a small environmentally influenced variation between the two members of the monozygotic twin pairs is implied The magnitude of these two variances relative to the other variances obtained for this measurement will assist in distinguishing between these alternatives The comparison of mean monozygotic (MZ) and mean dizygotic (DZ) variances provides a conventional test of a hereditary component of variability Absence of statistical significance in this ratio could be the result of either large environmental influences or small genetic variability between dizygotic twins Both the ME:MZ ratio and the DZ·IP ratio can then be used to help interpret the MZ:DZ ratio

While interpretation of the relative magnitude of the MZ.DZ and DZ·IP ratios is tempting, and some attempt at interpretation might provide interesting leads, it is necessary to take into consideration the variety of forces which could similarly affect these ratios With the present data these different forces cannot be distinguished. The presence of a strong genetic component of variability will decrease the magnitude of the monozygotic intrapair variance relative to both the dizygotic and interpair variances If few independent loci are involved, an increase in the dizygotic intrapair variance relative to the interpair variance would result; many independent loci would tend to decrease the dizygotic intrapair variance while increasing the interpair variance Similar effects would be found with common or rare genetic determinants. If the character under study is strongly influenced by the environment, the monozygotic intrapair variance is increased, and in general there will be a decrease in the dizygotic intrapair variance relative to the interpair variance A correlation between parents of twins for the character measured will not affect the monozygotic intrapair differences, but may decrease the dizygotic intrapair variance relative to the interpair variance.

The use of measurement error variances and interpair variances makes it possible to extend considerably the interpretation of twin data. With separate analyses of males and females, it is not necessary either to correct statistically for sex difference or to assume the absence of a sex influence upon trait variability. In fact, separation of the sexes makes it pos-

sible to test for sex influences and sex differences. A comparison of male and female monozygotic twins' mean variances offers a test for sex influences upon extragenic effects, and a similar comparison of mean variances of dizygotic twins gives a test of sex influences upon genetic differences Unlike sex pairs have the same average difference in their autosomal inheritance as do like sex dizygotic twins, and therefore provide data for testing actual sex differences. The comparability of measurement error, intrapair variances, and interpair variances also makes it possible to visualize the relative magnitude of the different components of variance by simple subtraction.[2]

Because the magnitude of the differences between the two members of any twin pair are small relative to those observed between different racial groups, or even between unrelated individuals in the same population, accuracy of measurement is of utmost importance To avoid differences in measurement technique, every subject was measured by the same anthropometrist (RHO) Both members of every twin pair were measured at the same time to eliminate diurnal variation[3] from the intrapair measurement differences Measurement error was determined by measuring volunteer subjects twice, thus duplicating the procedure employed with the twin pairs A full set of measurements was taken, set aside, and after a brief period repeated, simulating so far as possible the procedure with the twins As some drift in technique is likely to occur, these measurement checks on volunteer subjects were spaced throughout the course of the study

Following the evaluation of individual measurements, the interrelations among different measurements become of interest. While the sizes or dimensions of many parts of the body depend on the fact that there is an average or aggregate rate of growth common to the whole organism, there are also differences in rate between one part and another (Thompson, 1952) Because of the complex influence these features of growth and development have upon the magnitude of different measurements and their interrelationships, anthropologists have traditionally employed ratios of measurements to permit

[2] Error variance is given directly, environmental variance can be obtained by subtracting ME variance from MZ variance and genetic variance is obtained by subtracting MZ variance from DZ variance The variance due to dissimilar hereditary and environmental background (extra-familial variance) can be estimated by subtracting DZ variance from IP variance

[3] D'Arcy Thompson (1952, p 93) "Gravity makes a difference to a man's height, and no slight one, between the morning and the evening, it leaves its mark in sagging wrinkles, drooping mouth, and hanging breasts, it is the indomitable force which defeats us in the end, which lays us on our deathbed and lowers us to the grave"

meaningful comparison of measurements of people of different size or proportion.

In anthropometry these ratios or "indices" are expressed in terms of the percentage relation of one measurement to another These indices are simple expressions of the geometric relation of two dimensions, conveying to the anthropometrist an idea of the shape or relative size of the parts (Hrdlicka, 1947) Indices are calculated on correlated parts, as most parts of an individual are correlated and the number of possible measurements is legion, there is almost no limit to the number of different indices which can be and have been calculated A number of indices, however, have been extensively used both descriptively and comparatively, such as. "index ponderalis Levi" (*cube root of weight × 100/total height*), and the "cephalic index" (*head breadth × 100/head length*) We have calculated the most extensively used of these indices on our data, and have made the same variance analysis that was employed with the absolute measurements Index values can be treated as though they are absolute measurement values, with *x* becoming the difference between the two members of a twin pair for a particular index.

Although indices are useful for expressing the interrelations of two measurements, they tell very little about the actual nature of these interrelations One promising method of examining the nature of the interrelations is the "cross-twin analysis" (see Chapter II) This method potentially makes it possible to determine whether two different measurements are independent mechanically, physiologically, or genetically (Lerner, 1950) The strength of the relations between two measurements is examined within the same individual and between the two members of a twin pair To obtain the within-individual relations between two measurement values, such as height and weight, one member of each twin pair is taken at random (monozygotic, dizygotic, and male and female twin pairs are considered separately), and the interrelation between each individual's height and weight is established. The height measurement of each of these individuals is then compared with the weight of his co-twin to obtain a cross-twin value for the interrelations of height and weight. In monozygotic twin pairs, the cross-twin values provide a measure of the importance of factors acting alike upon height and weight in two different, though genetically identical, individuals Comparison of the monozygotic cross-twin values with the within-individual values permits the evaluation of the relative importance of the within-individual environment upon

the interrelations of height and weight. The same analysis in dizygotic twins tests the association between these two measurements in genetically different, though related, individuals of the same age. Finally, comparison of the dizygotic cross-twin values with the within-individual and monozygotic cross-twin values indicates the importance of the genetic factors relative to the environmental factors in height and weight.

The statistical device used to indicate the correlation or association between measurements in the cross-twin analysis is the correlation coefficient. In using this coefficient, certain precautions necessary for small samples have been observed. Conclusions were based upon the values of the calculated probabilities, and where it became desirable to interpret the relative importance of correlations of different sizes, z values were used (Fisher, 1954). Furthermore, the correlations calculated were between measurements which, for some biological reason, or as a result of previous studies, have been found to be meaningful. While interpretation of the cross-twin analysis of the present data is necessarily limited, certain interesting patternings will be seen repeatedly through its application

The methods which have been described briefly here were applied in the analysis which follows

Part Four

The Analysis of Morphological Variation

Chapter IX

Stature, Weight, and Ponderal Index

The most inclusive measures of human morphology are stature and weight, which are the principal measurements of size or the accumulative effect of growth. Because size is the most striking feature of growth and also one of the most conspicuous differences between people, stature and weight are the most commonly obtained measurements of morphological variation, they will therefore be the first aspects of our study to be considered

STATURE

Stature was measured with an anthropometer to the nearest millimeter, the subject standing bare-foot and stretching to maximum height with the head held in the Frankfort plane The effect of diurnal variation in stature (Tanner, 1950, De Puky, 1935) was reduced by the concurrent study of both members of a twin pair Intrapair variances therefore consist of mechanical measurement error and the results of environmental and genetic influences In spite of the small monozygotic stature variances, the accuracy of this measurement makes it possible to determine environmental effect (Table 10a). It should be pointed out that the sizable dif-

ference between the male and female ME·MZ ratios is not a consequence of a sex difference in response to environmental influences, but is due, in this case, to the greater accuracy of this measurement in females With a two-tail test of the differences between these two error variances, P< 05, a similar difference between the sexes is noted in all measurements requiring the subjects' physical cooperation in application of the measurement technique

The MZ:DZ and DZ IP comparisons are highly significant in both males and females, showing a strong hereditary component of variation in stature Interestingly, the relative magnitudes of the MZ·DZ and DZ.IP ratios are reversed in males and females as a result of a larger female DZ variance and a larger male IP variance Table 10b indicates that while the female DZ variance is larger than that of the males, it is *not* significantly larger Both sexes *in* the DZ category differ significantly from the unlike sex pairs, demonstrating the influence of sex upon stature. The difference between the male and female IP variances is not statistically significant, but there is a suggestion that the variance of stature is greater for males in this population than it is for females, and certainly a significant sex difference is seen

Table 10a.

Stature mean variances

	n	*Variance*	*F ratio*	*P**
Male				
Measurement error	7	084		
ME MZ			19 10	< 001
Monozygotic	25	1 604		
MZ DZ			4 73	< 001
Dizygotic	10	7 581		
DZ IP			15 26	< 001
Interpair	9	115 686		
Female				
Measurement error	21	028		
ME MZ			49 54	< 001
Monozygotic	34	1 387		
MZ DZ			13 22	< 001
Dizygotic	27	18 329		
DZ IP			2 84	005
Interpair	26	52 055		

Table 10b.

Stature sex comparison

	n	*Variance*	*F ratio*	*P**
Monozygotic				
Male	25	1 604		
♂♂ ♀♀			1 16	> 25
Female	34	1 387		
Dizygotic				
Male	10	7 581		
♂♂ ♀♀			2 42	< 25
Female	27	18 329		
Dizygotic				
Male	10	7 581		
♂♂ ♂♀			15 14	< 001
Unlike sex	16	114 789		
♂♀ ♀♀			6 26	< 001
Female	27	18 329		

* The greater than (>) or less than (<) sign is applied to the nearest percentage point given by Pearson and Hartley (1956) 0 25, 0 10, 0 05, 0 025, 0 01, 0 005, 0 001

WEIGHT

While adult stature represents a more or less permanent, and therefore reliable, measurement of the accumulative effect of growth, the second size measurement, adult weight, is subject to constant change Following the growth period, fat tends to deposit, and many factors, genetic as well as environmental, which previously were largely suppressed by other factors influencing or regulating growth rates, may then affect weight

In all studies of growing children, monozygotic and dizygotic twins have been found to differ significantly in weight except at birth The fact that accurate birth weights are more difficult to obtain than weights at a later age could conceivably account in part for this finding Also as pointed out by Robson (1955), and previously discussed here, the relation of fetal physiology of twins to birth weight is extremely complex Most important, however, is the fact that the majority of studies of birth weight have employed the Weinberg formula in lieu of actual zygosity diagnosis (Penrose, (1954), a procedure which in all probability introduces serious error

In the present study, the juvenile twin series, discussed previously, provided an unusual opportunity for testing birth weight differences All twin pairs were born in the same hospital over a relatively short period and were included in a special obstetric and pediatric study, the Fetal Life Study (McIntosh et al., 1954) There were 14 pairs of monozygotic and 16 pairs of like sex dizygotic twins in this series for whom a diagnosis of zygosity was obtained (see Appendix II). With a correction for sex and race, the F ratio for birth weight was 3 65, $P = 01$. For the same twin pairs at one year of age, an F ratio for weight was 3 74, $P < 01$ It is possible that this significant difference between monozygotic and dizygotic mean intrapair birth weights is the result of more uniform data than are usually available. Birth weights ranged from 1670 grams to 3350 grams, the mean intrapair differences of monozygotic twins was only 207 07 grams, and that of dizygotics 340 31 grams Even relatively small recording errors, or an error in the approximation of zygosity by the Weinberg formula, could easily obscure these small but significant differences between the two types of twins.

In adult subjects, with diurnal variations eliminated, weight is an accurate measurement when taken on a hospital balance scale Weight was recorded to the nearest pound with the subject clothed only in a hospital examining gown. Since care was taken in balancing the indicator

mechanism, only scale error could occur, measurement error variance, therefore, was not calculated. Table 11a shows significant ratios only in the DZ·IP comparisons. In Table 11b a large sex difference is shown in the dizygotic like sex and unlike sex ratios While the male MZ and IP variances are larger than the female, the DZ variance differences between the sexes is not proportionately as great as might have been expected on the basis of the findings for stature Since the DZ IP and dizygotic like sex and unlike sex ratios are roughly comparable in stature and weight, the most likely interpretation would appear to be that absence of a demonstrable hereditary effect in the MZ.DZ comparison is due to the strong environmental influences upon adult weight

The findings in respect to weight in the present data are in contrast to those of other twin studies, such as those by Clark (1956), and Newman, Freeman, and Holzinger (1937) It should be noted, however, that the median age of the subjects in Clark's study was 16 years, and in Newman's study 13 years. In the latter, the mean intrapair weight differences were 10.0 pounds for dizygotic twins and 4.0 pounds for monozygotic twins Newman had also obtained a sample of monozygotic twins raised in different foster homes; in this group in which the mean age was 26 years, the same

Table 11a.
Weight mean variances

	n	*Variance*	*F ratio*	*P*
Male				
ME MZ				
Monozygotic	25	62 400		
MZ DZ			1 05	> 25
Dizygotic	10	65 450		
DZ IP			5 91	> 005
Interpair	9	386 716		
Female				
Measurement error				
ME MZ				
Monozygotic	34	38 515		
MZ DZ			1 73	>.05
Dizygotic	27	66 722		
DZ IP			3 93	< 001
Interpair	26	262 510		

Table 11b.
Weight sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	62 400		
♂♂ ♀♀			1 62	> 25
Female	34	38 515		
Dizygotic				
Male	10	65 450		
♂♂ ♀♀			1 02	> 25
Female	27	66 722		
Dizygotic				
Male	10	65 450		
♂♂ ♂♀			9 25	< 001
Unlike sex	16	605 469		
♂♀ ♀♀			9 07	< 001
Female	27	66 722		

as that of monozygotic twins in our study, the mean intrapair weight difference was 9 9 pounds, fairly close to the difference we found, 8 2 pounds. It can be concluded that in the twin studies of growing children the hereditary influence measured by intrapair weight differences is principally associated with growth rate. Such a conclusion is in accordance with Thompson's statement (1952, p. 130). " . . this correlation passes through alternate maxima and minima, chief among which are a maximum at about fourteen years of age and a minimum about twenty-one " It may indicate that part of what the previous studies measured was the correlation of weight with stature, which is strongly influenced by genetic factors.

Because change in weight with age is a common observation in the adult, we decided to test the relationship of intrapair weight differences with age for the adult twins Calculations of the regression of intrapair weight differences on age were made separately for monozygotic and dizygotic twin pairs, following the method presented by Mather (1947) The regression coefficient for both monozygotic and dizygotic pairs was found to be only 0 12 lb /year, far short of any statistical significance for the rate of change of intrapair weight differences with age The environmental factors which prevent demonstration of a hereditary component of variability for weight in the present study do not appear to include age

PONDERAL INDEX

Numerical indices based on height and weight have been variously calculated in anthropology, in physiological correlations, and in other studies where a simple index of shape or "build" is desired The most frequently used of these indices is *height*/$\sqrt[3]{weight}$, commonly referred to as the "ponderal index" (though technically this should be called the "reciprocal ponderal index"). The purpose of this index is to equate weight and stature in proportion to the weight change normal for a given increment of stature For example, an individual 68 inches tall, weighing 143 pounds, will have a ponderal index of 13 0, as will a person one inch taller weighing 150 pounds. A man 72 inches tall weighing 170 pounds and a man 66 inches tall weighing 131 pounds will each have a ponderal index of 13 0 This is an index of shape, and as it excludes gross body size, it has value for certain purposes, though it does not take

Table 12

Ponderal index mean variances

	n	Variance	F ratio	P
Male				
Monozygotic	25	028		
MZ DZ			1 50	< 25
Dizygotic	10	042		
DZ IP			8 24	> 001
Interpair	9	346		
Female				
Monozygotic	34	036		
MZ DZ			2 22	< 025
Dizygotic	27	080		
DZ IP			4 26	< 001
Interpair	26	341		

Table 13.

Correlation between height and weight

	n	r	P
Male			
Monozygotic			
Individual	25	323	10
Cross-twin	25	361	05-10
Dizygotic			
Individual	10	415	> 10
Cross-twin	10	420	> 10
Female			
Monozygotic			
Individual	34	455	005-01
Cross-twin	34	486	001-005
Dizygotic			
Individual	27	388	02-05
Cross-twin	27	300	> 10

into account the complex biological interrelations of height and weight.

In the analysis of ponderal index (Table 12), comparison of monozygotic and dizygotic intrapair variances provides small F ratios The interpair variances, on the other hand, are relatively large, giving highly significant F ratios. The large interpair variances relative to the dizygotic intrapair variances might be due to a variety of causes (Chapter VIII), but it is clear that to obtain statistically measurable variability in the ponderal index requires the magnitude of forces affecting height and weight found between unrelated people in an adult population. The cross-twin analysis (Table 13) tends to confirm the above conclusions, and suggests, as does the variance analysis, that the ponderal index may be more meaningful in females Correlations are only moderate and they are equal in all comparisons; z transformations provide no significant differences in any of the comparisons.

CONCLUSIONS DRAWN FROM STATURE, WEIGHT, AND PONDERAL INDEX STUDIES

Inspection of the height, weight, and ponderal index intrapair differences revealed that in approximately half (31) of the monozygotic twin pairs

the taller member of the pair was the lighter, and that in 28 pairs the taller member was the heavier When the taller twin is the lighter, even small intrapair *differences in stature* and weight result in comparatively large intrapair differences in ponderal index This suggests that there may be a hereditary component for gross size, involving some proportionality of height and weight, that is not described by the ponderal index In fact, a hereditary component of gross size is to be anticipated on the bases of evolutionary evidence (Simpson, 1951) and of work by Howells (1951) and by others

To test whether the magnitude of the intrapair differences in weight is dependent upon the magnitude of the intrapair differences in stature (as is usually assumed because of the generally positive correlation of height and weight), 3 × 3 frequency tables were set up (Kempthorne, 1957), and three increments of intrapair height differences were plotted against three increments of intrapair weight differences. The chi-square values (with 4 d f) were:

Monozygotic male	$\chi^2 = 5.803$
Monozygotic female	$\chi^2 = 9\,479$
Dizygotic male	$\chi^2 = 5\,069$
Dizygotic female	$\chi^2 = 0\,441$

None of these values is statistically significant, though the monozygotic female value is just at the 0 05 level, therefore, there is no evidence here that the amount of intrapair difference in weight is dependent upon the amount of intrapair difference in *height*.

If two people are of the same stature, the heavier individual will have the smaller ponderal index We have seen that in monozygotic twin pairs whether the taller or shorter member is the heavier occurs in the approximate ratio of 1·1 We have further found no evidence that the amount of intrapair difference in weight is dependent upon the amount of intrapair difference in stature Therefore, unless some genetically or at least physiologically determined proportionality between height and weight exists, or there is a gross size factor, the relative magnitude of the ponderal index should be independent of whether a twin is the heavier or the lighter member of the twin pair. Taking a 1 1 ratio of heavier to lighter twin with the large ponderal index, we have tested the observed numbers in 2 × 2 contingency tables:

Monozygotic males
$\chi^2 = 9\,846 \quad P = 0\,0017$
Monozygotic females
$\chi^2 = 18.939 \quad P < \;001$
Dizygotic males
$\chi^2 = 0 \quad P = 1\,0$
Dizygotic females
$\chi^2 = 4\,481 \quad P = 0\,035$

The observed departures from ran-

domness in monozygotic twins is obviously highly significant; in dizygotic twins much smaller values are obtained with only borderline significance in dizygotic females. From this it would appear that there is a strong genetic component for either gross size or height-weight proportionality which is not described by the ponderal index.

A strong component of variability in adult stature is demonstrated in Table 10a, as well as the purely sex effect in Table 10b Weight, on the other hand, is less readily interpreted With uniform birth data, and an actual zygosity diagnosis, it is possible to demonstrate that intrapair differences of monozygotic twins differ significantly from those of dizygotic twins. Significant differences were obtained also for the same twin pairs at one year of age. Other twin studies have shown statistically significant differences between the intrapair differences of monozygotic and dizygotic twins up through and including adolescence In the adult pairs investigated here (Table 11a) *no* significant differences were found, and it is suggested that after the end of the growth period, weight, in essentially healthy people, is predominantly under environmental influence. An analysis of the ponderal index (Table 13) reveals that it is an ineffective measure of genetic variability. Our findings further emphasize the complex relation between height and weight, and we suggest that there may well be a gross size factor, or proportionality of height and weight, which has a sex and genetic component; this factor is largely lost in calculation of ponderal index. Certainly these data indicate that before the ponderal index can be effectively used in genetic studies, or in any studies of morphology, other than as a means of removing the element of gross size, we need to know a great deal more about the complex interrelations of height and weight.

Chapter X

Anthropometry

The traditional approach in anthropometry has been described by Hrdlicka "Scientific anthropometry, meaning merely systematized judicious observing and measuring, is limited only by the nature and scope of the problems to which it is applied. What regulations, divisions, indices, boundaries, and classifications it presents are all man-made and conventional, not natural" (Hrdlicka, 1947, p 5) With application of genetic principles to the study of man, emphasis has been increasingly placed upon the "natural" rather than the "conventional," and this also has importance for the application of anthropometric methods (Washburn, 1953). Man, like all other living organisms, is an adapted system, and measurements of his variation, as well as the divisions and classifications which are derived from these measurements, must accord to some extent with his adaptive form to have real biological meaning. In the present analysis, therefore, a sequential arrangement of measurements which reflects some natural or adaptive order is followed

The natural and adaptive divisions of the body can be derived from evolutionary evidence (Washburn, 1951), and they have been consistently verified by studies of growth and body form (McCloy, 1940; Howells, 1952, and others). Ideally these divisions should be. (1) arms and thorax, (2) pelvis and legs, (3) head and neck, but we cannot dissect the body in quite this manner by our

measurement techniques. The divisions we have used, therefore, are: (1) arm and hand, (2) trunk, (3) leg and foot, (4) head and neck. Within each of these divisions the measurements will be listed as measurements of: (a) length, (b) breadth and depth, (c) circumference. Here, as in the analysis of height, weight, and ponderal index, the first part of each table (a) will compare measurement error variance, the intrapair variance of monozygotic and like sex dizygotic twins, and the interpair variances of the like sex dizygotic twins. The second part of each table (b) will compare sex differences. The most critical, or at least commonly computed, indices have been calculated and analyzed, and will be presented and discussed following the analysis of the different measurements. When appropriate, a cross-twin analysis also has been made.

The measurement techniques employed were those of Hrdlicka (1949) as modified by Hooton. All measurements were made by the senior author. One member of a twin pair was measured completely and the co-twin was then measured without reference to the measurements of the first member of the pair. Male subjects were clothed in shorts, and female subjects in muslin slips. The numbers of pairs vary for different measurements. For male monozygotic twins $n = 24$ instead of 25 in many instances, because it was not possible to obtain all measurements on one twin pair due to lack of cooperation. In certain measurements the numbers vary as a result of particular circumstances.

ARM AND HAND MEASUREMENTS

Length

Total arm length (acromion to dactylion) This measurement, like stature, is a summation of the linear measurements of different segments. In spite of a low MZ variance, the accuracy is sufficient to measure individual differences in monozygotic twins. A strong hereditary component of variability is demonstrated in the MZ:DZ comparison (Table 14a). There is no significant sex influence in either the MZ or DZ variances and a strong sex difference is shown in the unlike sex comparison (Table 14b).

Upper arm length (acromion to radiale) The variances are comparable in males and females, and, with larger numbers, a measurable component of environmental variance can be detected in females. In both males and

Table 14a
Total arm length mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	166		
ME MZ			4 02	> 025
Monozygotic	25	668		
MZ DZ			4 97	< 001
Dizygotic	10	3 321		
DZ IP			3 92	< 025
Interpair	9	13 026		
Female				
Measurement error	21	076		
ME MZ			10 58	< 001
Monozygotic	34	804		
MZ DZ			7 54	< 001
Dizygotic	27	6 063		
DZ IP			2 05	< 05
Interpair	26	12 398		

Table 14b
Total arm length sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	668		
♂♂ ♀♀			1 20	> 25
Female	34	804		
Dizygotic				
Male	10	3 321		
♂♂ ♀♀			1 83	> 25
Female	27	6 063		
Dizygotic				
Male	10	3 321		
♂♂ ♂♀			7 43	> 001
Unlike sex	16	24 684		
♂♀ ♀♀			4 07	< 001
Female	27	6 063		

females, there is a measurable component of inherited variation (Table 15a) The sex influences and differences are almost exactly comparable to those in total arm length (Table 15b).

Forearm length (radiale to stylion)

Hand length (stylion to dactylion)

Middle finger length (crease at base of finger to dactylion)

The variances for each of these three measurements are similar to those of the upper arm, though the inherited component is less in the female hand *It appears that the hereditary and* environmental components of variation are approximately equal in each segment of the arm and hand When these segments are then combined into the single measurement of arm length, large variances with good statistical reliability are obtained (Tables 16a, 17a, 18a) The sex influences and differences are also similar to those in the upper arm, though the smaller inheritance factor for the female, due mainly to a large monozygotic variance, results in a significant sex influence factor The greater male variability in mid-finger length also gives an insignificant sex difference in the unlike sex comparison. *If the IP variances of males and fe*males for finger length are compared, an F ratio is obtained with $P<.05$ (Tables 16b, 17b, 18b)

Table 15a
Upper arm length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	109		
ME MZ			2 90	< 10
Monozygotic	25	316		
MZ DZ			2 68	025
Dizygotic	10	846		
DZ IP			3 08	05
Interpair	9	2 604		
Female				
Measurement error	21	111		
ME MZ			3 32	< 005
Monozygotic	34	369		
MZ DZ			2 58	< 01
Dizygotic	27	953		
DZ IP			2 56	01
Interpair	26	2 437		

Table 16a
Forearm length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	158		
ME MZ			1 69	25
Monozygotic	25	267		
MZ DZ			2 89	< 025
Dizygotic	10	771		
DZ IP			2 09	> 10
Interpair	9	1 610		
Female				
Measurement error	21	130		
ME MZ			2 19	< 05
Monozygotic	34	285		
MZ DZ			3 11	> 001
Dizygotic	27	885		
DZ IP			4 23	< 001
Interpair	26	3 743		

Table 15b
Upper arm length sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	316		
♂♂ ♀♀			1 17	> 25
Female	34	369		
Dizygotic				
Male	10	846		
♂♂ ♀♀			1 13	> 25
Female	27	953		
Dizygotic				
Male	10	846		
♂♂ ♂♀			5 03	> 005
Unlike sex	16	4 256		
♂♀ ♀♀			4 47	< 001
Female	27	953		

Table 16b.
Forearm length sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	267		
♂♂ ♀♀			1 07	> 25
Female	34	285		
Dizygotic				
Male	10	771		
♂♂ ♀♀			1 15	> 25
Female	27	885		
Dizygotic				
Male	10	771		
♂♂ ♂♀			3 71	< 025
Unlike sex	16	2 859		
♂♀ ♀♀			3 23	< 005
Female	27	885		

Table 17a. *Hand length mean variances*

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	106		
ME MZ			1 32	> 25
Monozygotic	25	140		
MZ DZ			3 44	> 005
Dizygotic	10	482		
DZ IP			4 11	< 025
Interpair	9	1 983		
Female				
Measurement error	21	073		
ME MZ			4 56	< 001
Monozygotic	33	333		
MZ DZ			1 58	> 10
Dizygotic	27	527		
DZ IP			2 79	> 005
Interpair	26	1 468		

Table 18a *Middle finger length mean variances*

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	006		
ME MZ			3 50	< 05
Monozygotic	24	021		
MZ DZ			7 76	< 001
Dizygotic	10	163		
DZ IP			3 67	> 025
Interpair	9	598		
Female				
Measurement error	21	008		
ME MZ			2 88	< 01
Monozygotic	33	023		
MZ DZ			3 91	< 001
Dizygotic	27	090		
DZ IP			2 48	> 01
Interpair	26	223		

Table 17b. *Hand length sex comparison*

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	140		
♂♂ ♀♀			2 38	025
Female	33	333		
Dizygotic				
Male	10	482		
♂♂ - ♀♀			1 09	> 25
Female	27	527		
Dizygotic				
Male	10	482		
♂♂ - ♂♀			4 12	> 01
Unlike sex	16	1 985		
♂♀ ♀♀			3 77	> 001
Female	27	.527		

Table 18b *Middle finger length sex comparison*

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	021		
♂♂ ♀♀			1 10	> 25
Female	33	023		
Dizygotic				
Male	10	163		
♂♂ ♀♀			1 81	> 25
Female	27	090		
Dizygotic				
Male	10	163		
♂♂ ♂♀			1 67	< 25
Unlike sex	16	272		
♂♀ ♀♀			3 02	> 005
Female	27	090		

Breadth

Wrist breadth (bistyloid)

This is an accurate measurement which permits the detection of an extremely small intrapair variance in monozygotic twins. The MZ DZ comparison shows a strong hereditary component of variability, in the light of which the IP variances are surprisingly low. The results obtained with this dimension suggest that the breadth at the elbow might also be of interest The latter was not taken, however, because of the difficulty in obtaining accurate and consistent measurements at that point (Table 19a). There are no strong sex influence factors and only moderate sex differences in the unlike sex comparisons (Table 19b).

Hand breadth (palm)

The low MZ and DZ variances, together with the relatively larger IP variances, suggested to the anthropometrist that perhaps too great pressure was used in taking this measurement, with the result that only the large differences which occur between unrelated individuals were adequately measured (Table 20a) The large sex differences which were of sufficient magnitude to be revealed by use of this technique for measuring hand breadth were to be expected (Table 20b).

Table 19a.
Wrist breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	002		
ME, MZ			7 50	> 005
Monozygotic	25	.015		
MZ DZ			4 60	< 001
Dizygotic	10	069		
DZ IP			1 59	25
Interpair	9	110		
Female				
Measurement error	21	006		
ME MZ			3 17	< 005
Monozygotic	34	019		
MZ DZ			5 47	< 001
Dizygotic	27	104		
DZ IP			1 29	> 25
Interpair	26	134		

Table 19b
Wrist breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	015		
♂♂ ♀♀			1 27	> 25
Female	34	019		
Dizygotic				
Male	10	069		
♂♂ ♀♀			1 51	> 25
Female	27	104		
Dizygotic				
Male	10	069		
♂♂ ♂♀			3 33	> 025
Unlike sex	16	230		
♂♀ ♀♀			2 21	< 05
Female	27	104		

Table 20a.
Hand breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	022		
ME MZ			2 23	> 10
Monozygotic	25	049		
MZ DZ			45	< 90
Dızygotic	10	022		
DZ IP			11 32	< 001
Interpaır	9	249		
Female				
Measurement error	21	024		
ME MZ			1 29	> 25
Monozygotic	34	031		
MZ DZ			1 61	10
Dızygotic	27	050		
DZ IP			15 14	< 001
Interpaır	26	757		

Table 20b.
Hand breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	049		
♂♂ ♀♀			1 58	> 25
Female	34	031		
Dızygotic				
Male	10	022		
♂♂ ♀♀			2 27	< 25
Female	27	050		
Dızygotic				
Male	10	022		
♂♂ ♂♀			24 23	< 001
Unlike sex	16	533		
♂♀ ♀♀			10 66	< 001
Female	27	050		

Circumference

Upper arm cırcumference (greatest below trıceps)

The larger male ME varıances ın this and the following measurement are at least ın part the consequence of the tendency of the males to tense their muscles for a circumference measurement Thıs measurement includes subcutaneous fat, and the contrast of these IP varıances wıth those of the upper arm fat calıper measurement of Table 78a would ındıcate a rather complex factor relating to the dıfferent tissues included ın thıs measurement. While the measurement of an ınherıtance factor is very poor here, ıt does reflect the same sex difference seen ın Table 78 (Table 21a) The MZ and DZ varıances show no sıgnificant sex ınfluence, but the sex dıfference in the unlıke sex comparıson ıs strong (Table 21b)

Forearm cırcumference (greatest of mıd-forearm)

Forearm circumference is much more ındicative of hereditary variabılity in both males and females than is upper arm circumference (Table 22a). Sex appears to be the most important factor in forearm cırcumference (Table 22b)

Mınımal wrıst cırcumference

In the female the gradual taper of the wrist makes the findıng of mın-

imal circumference difficult, and this difficulty probably accounts for both the higher measurement error and the lower monozygotic variance obtained The total amount of measurable variance in the male wrist is small, and it might be hypothesized that the significant feature in the female wrist is taper rather than variance in circumference (Table 23a) Although there is no sex influence, there is a strong sex difference (Table 23b)

Summary of findings on arm and hand

Total arm length (Table 14), taken from acromion to dactylion, is an accurate measurement, and provides good indication of a genetic component of variability The variability in the two sexes is roughly comparable, not significantly sex-influenced but showing strong sex differences The different segments which constitute total arm length, with the apparent exception of hand length in females, also give very satisfactory results. Middle finger length is a surprisingly good measure of genetic variability. Wrist breadth, or bistyloid breadth, also proves to be an extremely accurate and good measure of genetic variability in both males and females, with a relatively small, though statistically significant, sex difference. The arm circumference measurements are found to be accurate, but in our data do not measure

Table 21a. Upper arm circumference mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	200		
ME MZ			5 60	> 01
Monozygotic	24	1 120		
MZ DZ			1 36	> 25
Dizygotic	10	1 528		
DZ IP			1 63	< 25
Interpair	9	2 485		
Female				
Measurement error	21	093		
ME MZ			9 87	< 001
Monozygotic	34	918		
MZ DZ			1 58	> 10
Dizygotic	27	1 454		
DZ IP			4 72	< 001
Interpair	26	6 859		

Table 21b. Upper arm circumference sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	1 120		
♂♂ ♀♀			1 22	> 25
Female	34	918		
Dizygotic				
Male	10	1 528		
♂♂ ♀♀			1 05	> 25
Female	27	1 454		
Dizygotic				
Male	10	1 528		
♂♂ ♂♀			6 08	< 005
Unlike sex	16	9 293		
♂♀ ♀♀			6 39	< 001
Female	27	1 454		

Table 22a. Forearm circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	173		
ME MZ			4 12	> 025
Monozygotic	24	712		
MZ DZ			26	< 975
Dizygotic	10	184		
DZ IP			12 09	< 001
Interpair	9	2 224		
Female				
Measurement error	21	071		
ME MZ			4 87	< 001
Monozygotic	34	346		
MZ DZ			2 64	< 01
Dizygotic	26	912		
DZ IP			1 92	05
Interpair	25	1 750		

Table 23a Minimal wrist circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	004		
ME MZ			25 50	< 001
Monozygotic	24	102		
MZ DZ			1 67	> 10
Dizygotic	10	170		
DZ IP			3 77	025
Interpair	9	640		
Female				
Measurement error	21	031		
ME MZ			1 90	< 10
Monozygotic	34	059		
MZ DZ			4 63	< 001
Dizygotic	27	273		
DZ IP			3 68	< 001
Interpair	26	1 004		

Table 22b. Forearm circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	712		
♂♂ · ♀♀			2 06	05
Female	34	346		
Dizygotic				
Male	10	184		
♂♂ · ♀♀			4 96	> 01
Female	26	912		
Dizygotic				
Male	10	184		
♂♂ ♂♀			43 90	< 001
Unlike sex	16	8 078		
♂♀ ♀♀			8 86	< 001
Female	26	912		

Table 23b. Minimal wrist circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	102		
♂♂ ♀♀			1 73	> 10
Female	34	059		
Dizygotic				
Male	10	170		
♂♂ ♀♀			1 61	> 25
Female	27	273		
Dizygotic				
Male	10	170		
♂♂ ♂♀			9 72	< 001
Unlike sex	16	1 653		
♂♀ ♀♀			6 05	< 001
Female	27	273		

Table 24. Correlation between upper arm length and forearm length

	n	r	P
Male			
Monozygotic			
Individual	25	712	< 001
Cross-twin	25	750	< 001
Dizygotic			
Individual	10	604	05–10
Cross-twin	10	592	05–10
Female			
Monozygotic			
Individual	34	732	< 001
Cross-twin	34	652	< 001
Dizygotic			
Individual	27	683	< 001
Cross-twin	27	220	> 10

Table 25. Correlation between forearm length and wrist breadth

	n	r	P
Male			
Monozygotic			
Individual	25	217	> 10
Cross-twin	25	– 147	> 10
Dizygotic			
Individual	10	655	02–05
Cross-twin	10	122	> 10
Female			
Monozygotic			
Individual	34	.524	001–005
Cross-twin	34	581	< 001
Dizygotic			
Individual	26	429	02–05
Cross-twin	26	239	> 10

genetic variability although they describe large sex differences.

The brachial index (forearm length *to upper arm length) gives an* MZ:DZ F ratio of 1 52, P< 25, in males, and 1 03, P>.25, in females. The cross-twin analysis of these two measurements (Table 24) gives evidence of relatively strong and significant correlations within individuals and between monozygotic twins The male dizygotic cross-twin correlation also is high, but with these numbers it is not statistically significant In females the dizygotic cross-twin correlation is considerably smaller, and on the basis of z transformations, the comparison of MZ cross-twin with DZ cross-twin gives t = 2 04, P = 0.02–0.05, the comparison of DZ cross-twin with DZ individual gives t = 2 12, P = 0.02–0.05. The correlation between these two arm segments is apparently the *result of other than just within-*individual environment. In all probability it can be assumed that there are genetic influences upon the covariation of these segments. It is interesting that the brachial index was the first anthropometric demonstration of morphological differences between races (White, 1794, as given by Wilder, 1920). While analysis of the brachial index gives no evidence of a genetic component of variability, the two measurements, taken separately, and the cross-twin analysis, indicate genetic influences on both the actual length of these two segments and their interrelations

Table 25 presents the cross-twin

analysis of forearm length and wrist breadth. In females both within-individual and MZ cross-twin correlations, while moderate, are statistically significant In monozygotic males this does not hold; in fact, there is a small negative correlation in the cross-twin comparison. In dizygotic males and females the pattern is comparable; it is the pattern to be anticipated from the results for monozygotic females. No significant differences between z transformations are found, but there is a suggestion of genetically influenced covariation subject to some influence to which monozygotic males are particularly susceptible. This influence will be observed in a number of measurements.

Of the arm and hand measurements, total arm length and wrist, or bistyloid, breadth seem to provide the most valuable measurements of genetically conditioned variability

TRUNK MEASUREMENTS

Length

Sitting height (measured to vertex with subject seated)

Suprasternal height (measured to suprasternal notch with subject seated)

These two measurements are nearly equivalent, but sitting height is a more accurate measurement than suprasternal As in stature, the sex differences in the ME:MZ ratios are mainly the result of the larger male measurement error, for the MZ variances are proportional in the two sexes Both sitting height and suprasternal height provide good measures of a hereditary component, the former being slightly better The DZ:IP ratios for females agree well with the same ratio for stature, while the male ratios do not. As these two measures are segments of stature, there is a suggestion here that their relative contributions to stature variance have a sex difference (Tables 26a and 27a). There is no apparent sex influence upon MZ and DZ variances in either measurement, but in the unlike sex comparison there is a strong indication of a sex difference (Tables 26b and 27b).

Breadth and Depth

Bideltoid breadth (maximal contact shoulder breadth)

Bi-acromial breadth (acromion point to acromion point)

Neither measurement provides a very satisfactory result, though they are readily repeatable on the same subject Of the two, bi-acromial appears to be slightly the better, in terms of both accuracy and the variance measured (Tables 28a and 29a) The magnitudes of the sex differences pro-

Table 26a
Sitting height mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	186		
ME MZ			2 81	< 10
Monozygotic	25	523		
MZ DZ			6 73	< 001
Dizygotic	10	3 522		
DZ IP			1 55	25
Interpair	9	5 451		
Female				
Measurement error	21	085		
ME MZ			5 18	< 001
Monozygotic	34	440		
MZ DZ			6 71	< 001
Dizygotic	27	2 950		
DZ IP			3 91	< 001
Interpair	26	11 535		

Table 27a.
Suprasternal height mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	419		
ME MZ			2 08	> 10
Monozygotic	25	870		
MZ DZ			4.57	> 001
Dizygotic	9	3 972		
DZ IP			1 189	> 25
Interpair	8	4 723		
Female				
Measurement error	21	195		
ME MZ			4 75	< 001
Monozygotic	33	927		
MZ DZ			3 21	> 001
Dizygotic	27	2 973		
DZ IP			2 28	< 025
Interpair	25	6 764		

Table 26b
Sitting height sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	523		
♂♂ ♀♀			1 19	> 25
Female	34	440		
Dizygotic				
Male	10	3 522		
♂♂ ♀♀			1 19	> 25
Female	27	2 950		
Dizygotic				
Male	10	3 522		
♂♂ ♂♀			5 95	< 005
Unlike sex	16	20 965		
♂♀ ♀♀			7 11	< 001
Female	27	2 950		

Table 27b.
Suprasternal height sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	870		
♂♂ ♀♀			1 07	> 25
Female	33	927		
Dizygotic				
Male	9	3 972		
♂♂ ♀♀			1 34	> 25
Female	27	2 973		
Dizygotic				
Male	9	3 972		
♂♂ ♂♀			2 32	< 10
Unlike sex	16	9 200		
♂♀ ♀♀			3 09	> 005
Female	27	2 973		

Table 28a.
Bideltoid breadth mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	341		
ME MZ			4 96	< 025
Monozygotic	25	1 690		
MZ DZ			77	> 75
Dizygotic	10	1 305		
DZ IP			3 36	< 05
Interpair	9	4 383		
Female				
Measurement error	21	275		
ME MZ			3 31	< 005
Monozygotic	34	910		
MZ DZ			1 14	> 25
Dizygotic	27	1 039		
DZ IP			4 14	< 001
Interpair	26	4 304		

Table 29a.
Bi-acromial breadth mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	191		
ME MZ			3 76	< 05
Monozygotic	25	719		
MZ DZ			2 29	< 05
Dizygotic	10	1 643		
DZ IP			3 31	< 05
Interpair	9	5 435		
Female				
Measurement error	21	278		
ME MZ			3 32	< 005
Monozygotic	34	923		
MZ DZ			1 40	> 10
Dizygotic	27	1 295		
DZ IP			3 57	< 001
Interpair	26	4 625		

Table 28b
Bideltoid breadth sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	1 690		
♂♂ ♀♀			1 86	> 10
Female	34	910		
Dizygotic				
Male	10	1 305		
♂♂ ♀♀			1 26	> 25
Female	27	1 039		
Dizygotic				
Male	10	1 305		
♂♂ ♂♀			10 51	< 001
Unlike sex	16	13 710		
♂♀ ♀♀			13 20	< 001
Female	27	1 039		

Table 29b.
Bi-acromial breadth sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	719		
♂♂ ♀♀			1 28	> 25
Female	34	923		
Dizygotic				
Male	10	1 643		
♂♂ ♀♀			1 27	> 25
Female	27	1 295		
Dizygotic				
Male	10	1 643		
♂♂ ♂♀			5 50	< 005
Unlike sex	16	9 041		
♂♀ ♀♀			6 98	< 001
Female	27	1 295		

vide highly significant ratios in the unlike sex pairs (Tables 28b and 29b)

Chest breadth (at level of fourth rib articulation)

Chest depth (at level of inferior border of scapula)
Like the shoulder measurements, chest breadth and depth measurements, though reasonably accurate, rather poorly indicate genetic variability. Breadth is better than the shoulder measurements, however, and chest breadth does significantly measure a hereditary component of variation in females (Tables 30a and 31a). Again sex differences are pronounced, particularly in chest breadth, and even the male and female IP variances reveal a highly significant sex difference (P< 005) (Tables 30b and 31b).

Waist width (minimal contact width, or at anatomical waist below border of thoracic cage)

Hip breadth (maximal contact breadth at level of iliac crest)
Waist width provides a better measurement of a hereditary component of variation than any other breadth measurement of the trunk Hip breadth, which measures the iliac crest fat pad in females, also provides good indication of both environmental and hereditary differences (Tables 32a and 33a) The variance

Table 30a.
Chest breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	.141		
ME MZ			3 06	> 05
Monozygotic	25	431		
MZ DZ			2 17	> 05
Dizygotic	10	933		
DZ IP			19 35	< 001
Interpair	9	18 051		
Female				
Measurement error	21	098		
ME MZ			6 31	< 001
Monozygotic	34	618		
MZ DZ			2 21	< 025
Dizygotic	27	1 370		
DZ IP			1 91	> 05
Interpair	26	2 611		

Table 30b.
Chest breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	431		
♂♂ ♀♀			1 43	> 25
Female	34	618		
Dizygotic				
Male	10	933		
♂♂ ♀♀			1 47	> 25
Female	27	1 368		
Dizygotic				
Male	10	933		
♂♂ ♂♀			10 12	< 001
Unlike sex	16	9 446		
♂♀ ♀♀			6 90	< 001
Female	27	1.368		

Table 31a
Chest depth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	047		
ME MZ			13 02	< 001
Monozygotic	25	612		
MZ DZ			1 83	10
Dizygotic	10	1 121		
DZ.IP			4 84	> 01
Interpair	9	5 423		
Female				
Measurement error	21	127		
ME·MZ			4 87	< 001
Monozygotic	34	618		
MZ DZ			1 20	> 25
Dizygotic	27	743		
DZ IP			6 61	< 001
Interpair	26	4 912		

Table 31b.
Chest depth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	612		
♂♂ ♀♀			1 01	> 25
Female	34	618		
Dizygotic				
Male	10	1 121		
♂♂ ♀♀			1 51	> 25
Female	27	743		
Dizygotic				
Male	10	1 121		
♂♂ ♂♀			2 62	> 05
Unlike sex	16	2 942		
♂♀ ♀♀			3 96	< 001
Female	27	743		

in waist width is sex influenced in both monozygotic and dizygotic twins, and the large female variance in hip breadth is sex influenced in dizygotic twins Because of the large variance, hip breadth does not measure sex difference in the female dizygotic to unlike sex comparison, and for the same reason waist width does not indicate sex difference in the male dizygotic to unlike sex comparison (Tables 32b and 33b).

Bi-iliac breadth (iliac crest to iliac crest)

Bitrochanteric breadth (maximal breadth in region of trochanter)

The individual differences between monozygotic twins are equivalent for the two sexes in both measurements, but both provide better indications of hereditary variance in females than in males In males these measurements are not as good as the shoulder measurements, but they appear to be better than the shoulder measurements in females (Tables 34a and 35a) There are no significant sex differences or influences for bi-iliac breadth, though there is a significant sex difference for bitrochanteric breadth (Tables 34b and 35b).

Circumference

Chest circumference (maximal contact circumference at level of the nipple)

Chest circumference at xiphoid process (seventh rib-sternum articulation)

Table 32a.
Waist width mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	157		
ME MZ			7 88	< 005
Monozygotic	24	1 237		
MZ DZ			4 71	< 001
Dizygotic	10	5 829		
DZ IP			3 48	> 025
Interpair	9	20 302		
Female				
Measurement error	21	106		
ME MZ			5 70	< 001
Monozygotic	33	604		
MZ DZ			2 68	> 005
Dizygotic	27	1 620		
DZ IP			6 01	< 001
Interpair	26	9 732		

Table 33a.
Hip breadth mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	208		
ME MZ			4 21	> 025
Monozygotic	24	875		
MZ DZ			67	>.75
Dizygotic	10	581		
DZ IP			11 01	< 001
Interpair	9	6 430		
Female				
Measurement error	21	,053		
ME MZ			15 58	< 001
Monozygotic	34	826		
MZ DZ			2 49	01
Dizygotic	27	2 053		
DZ IP			3 71	< 001
Interpair	26	7 625		

Table 32b
Waist width sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	1 237		
♂♂ ♀♀			2 05	05
Female	33	604		
Dizygotic				
Male	10	5 829		
♂♂ ♀♀			3 60	< 01
Female	27	1 620		
Dizygotic				
Male	10	5 829		
♂♂ ♂♀			1 84	< 25
Unlike sex	16	10 705		
♂♀ ♀♀			6 61	< 001
Female	27	1 620		

Table 33b
Hip breadth sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	875		
♂♂ ♀♀			1 06	> 25
Female	34	826		
Dizygotic				
Male	10	581		
♂♂ ♀♀			3 52	< 05
Female	27	2 053		
Dizygotic				
Male	10	,581		
♂♂ ♂♀			6 21	< 005
Unlike sex	16	3 621		
♂♀ ♀♀			1 77	< 10
Female	27	2 053		

Table 34a.
Bi-iliac breadth mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	176		
ME MZ			3 02	> 05
Monozygotic	25	531		
MZ DZ			1 50	> 10
Dizygotic	10	796		
DZ IP			6 18	< 005
Interpair	9	4 922		
Female				
Measurement error	21	077		
ME MZ			7 70	< 001
Monozygotic	34	593		
MZ DZ			2 29	< 025
Dizygotic	27	1 356		
DZ IP			2 83	005
Interpair	26	3 831		

Table 35a. Bitrochanteric breadth
mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	036		
ME MZ			17 44	< 001
Monozygotic	25	628		
MZ DZ			1 44	< 25
Dizygotic	10	903		
DZ IP			7 42	> 001
Interpair	9	6 704		
Female				
Measurement error	21	066		
ME MZ			11 05	< 001
Monozygotic	34	729		
MZ DZ			2 09	> 025
Dizygotic	27	1 525		
DZ IP			3 59	001
Interpair	26	5 468		

Table 34b
Bi-iliac breadth sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	531		
♂♂ ♀♀			1 12	> 25
Female	34	593		
Dizygotic				
Male	10	796		
♂♂ ♀♀			1 70	> 25
Female	27	1 356		
Dizygotic				
Male	10	796		
♂♂ ♂♀			1 44	> 25
Unlike sex	16	1 148		
♂♀ ♀♀			85	> 75
Female	27	1 356		

Table 35b Bitrochanteric breadth
sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	628		
♂♂ ♀♀			1 16	> 25
Female	34	729		
Dizygotic				
Male	10	903		
♂♂ ♀♀			1 69	> 25
Female	27	1 525		
Dizygotic				
Male	10	903		
♂♂ ♂♀			4 49	> 01
Unlike sex	16	4 053		
♂♀ ♀♀			2 66	> 01
Female	27	1 525		

Chest circumference at the nipple is an adequate measure of both hereditary and environmental variance in males, but probably describes only environmentally influenced variance in females. Circumference taken at the xiphoid process is not as good a measurement in males as circumference at the nipple, and is only questionably better in the females (Tables 36a and 37a) There is no sex difference for chest circumference at the nipple, apparently because the larger thorax in the male is equivalent to the increase in circumference due to breast development in the female Chest circumference at the xiphoid process, however, does provide a measure of sex difference (Tables 36b and 37b)

Table 36a. Chest circumference (at nipples) mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	499		
ME MZ			9 66	< 005
Monozygotic	24	4 822		
MZ DZ			3 19	01
Dizygotic	10	15 376		
DZ IP			2 96	> 05
Interpair	9	45 554		
Female				
Measurement error	21	598		
ME MZ			10 96	< 001
Monozygotic	31	6 554		
MZ DZ			1 56	> 10
Dizygotic	27	10 243		
DZ IP			8 36	< 001
Interpair	26	85 655		

Table 36b. Chest circumference (at nipples) sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	4 822		
♂♂ ♀♀			1 36	> 25
Female	31	6 554		
Dizygotic				
Male	10	15 376		
♂♂ ♀♀			1 50	> 25
Female	27	10 243		
Dizygotic				
Male	10	15 376		
♂♂ ♂♀			1 15	> 25
Unlike sex	15	17 685		
♂♀ ♀♀			1 73	10
Female	27	10 243		

Waist circumference (minimal waist without retraction, or anatomical waist below border of thoracic cage)

Hip circumference

Waist circumference in males has a wide range of variation which would appear to be influenced almost entirely by environment whereas in females waist circumference is a good measure of hereditary variability as well. These findings may reflect the sex differences in abdominal fat distribution. Hip circumference is an equally good measure in females, but poor in males (Tables 38a and 39a). Waist circumference is a good measure of sex difference but, surprisingly,

Table 37a. Chest circumference (at xiphoid process) mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	1 595		
ME MZ			3 34	> 05
Monozygotic	24	5 330		
MZ DZ			1 84	10
Dizygotic	10	9 792		
DZ IP			7 84	> 001
Interpair	9	76 721		
Female				
Measurement error	21	741		
ME MZ			7 94	< 001
Monozygotic	33	5 887		
MZ DZ			1 72	> 05
Dizygotic	27	10 116		
DZ IP			4 28	< 001
Interpair	26	43 291		

Table 37b. Chest circumference (at xiphoid process) sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	5 330		
♂♂ ♀♀			1 10	> 25
Female	33	5 887		
Dizygotic				
Male	10	9 792		
♂♂ ♀♀			1 03	> 25
Female	27	10 116		
Dizygotic				
Male	10	9 792		
♂♂ ♂♀			7 75	> 001
Unlike sex	16	75 849		
♂♀ ♀♀			7 50	< 001
Female	27	10 116		

hip circumference is not (Tables 38b and 39b)

Summary of findings on trunk

In general, measurements of the upper trunk have a stronger hereditary component of variability in males, and those of the lower trunk a stronger component in females. In females the circumference measurements of waist and hips particularly have a strong genetic component of variability The measurements which are best and most consistent in both sexes are sitting height and suprasternal height Suprasternal height provides slightly smaller F ratios than sitting height, but it has an advantage in that it is a measurement of trunk length only and does not include neck length and head height Contact measurements, such as bideltoid, hip breadth, waist width, and bitrochanteric breadth, can be made accurately, and in some instances they are better measures of genetic variability than are the more conventional measurements taken on bony points. A recurring pattern appears for many measurements in this region, as it does in the other regions Large ME.MZ ratios are frequently accompanied by large DZ:IP ratios In all probability this pattern is best interpreted as confirmatory evidence for both strong environmental influence and high modifiability of the structures measured Two good ex-

Table 38a.
Waist circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	1 350		
ME MZ			7 45	> 005
Monozygotic	24	10 060		
MZ DZ			1 38	25
Dizygotic	10	13 920		
DZ IP			9 26	< 001
Interpair	9	128 839		
Female				
Measurement error	21	505		
ME MZ			11 45	< 001
Monozygotic	34	5 781		
MZ DZ			2 31	> 01
Dizygotic	26	13 370		
DZ IP			7 34	< 001
Interpair	25	98 168		

Table 39a.
Hip circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	221		
ME MZ			26 79	< 001
Monozygotic	23	5 921		
MZ DZ			1 24	> 25
Dizygotic	9	7 313		
DZ IP			4 93	> 01
Interpair	8	36 077		
Female				
Measurement error	21	182		
ME MZ			20 68	< 001
Monozygotic	34	3 764		
MZ DZ			2 98	< 005
Dizygotic	27	11 210		
DZ IP			2 95	< 005
Interpair	26	33 070		

Table 38b
Waist circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	10 060		
♂♂ ♀♀			1 74	> 10
Female	34	5 781		
Dizygotic				
Male	10	13 920		
♂♂ ♀♀			1 04	> 25
Female	26	13 370		
Dizygotic				
Male	10	13 920		
♂♂ ♂♀			5 69	< 005
Unlike sex	16	79 240		
♂♀ ♀♀			5 93	< 001
Female	26	13 370		

Table 39b.
Hip circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	23	5 921		
♂♂ ♀♀			1 57	> 25
Female	34	3 764		
Dizygotic				
Male	9	7 313		
♂♂ ♀♀			1 53	> 25
Female	27	11 210		
Dizygotic				
Male	9	7 313		
♂♂ ♂♀			2 98	> 05
Unlike sex	16	21 814		
♂♀ ♀♀			1 95	> 05
Female	27	11 210		

Table 40 Correlation between chest breadth and bitrochanteric breadth

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	656	< 001
Cross-twin	25	638	< 001
Dizygotic			
Individual	10	748	01–02
Cross-twin	10	397	> 10
Female			
Monozygotic			
Individual	34	664	< 001
Cross-twin	34	654	< 001
Dizygotic			
Individual	27	445	02
Cross-twin	27	034	> 10

Table 41. Correlation between chest breadth and suprasternal height

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	067	> 10
Cross-twin	25	285	> 10
Dizygotic			
Individual	10	– 261	> 10
Cross-twin	10	285	> 10
Female			
Monozygotic			
Individual	32	367	02–05
Cross-twin	32	277	> 10
Dizygotic			
Individual	27	069	> 10
Cross-twin	27	– 075	> 10

amples are chest circumference in females (Table 36a), and waist circumference in both males and females (Table 38a).

Indices calculated *from trunk* measurements failed to give statistically significant differences between monozygotic and dizygotic twins. Bitrochanteric breadth to chest breadth gave the largest MZ·DZ *ratios. in* males 1 97, P<0.10, and in females 2 05, P<0 05 The cross-twin analysis of these two measurements is presented in Table 40. Moderate and statistically significant correlations are found within individuals and the monozygotic cross-twin comparison The dizygotic cross-twin correlations are small and not statistically significant. Again there is evidence of genetically influenced covariation of two measurements In females the MZ cross-twin to DZ cross-twin comparison provides a t = 2 75, P = 0 005-0 01, and the DZ cross-twin to DZ *individual comparison* gives t = 1 537, P = 0 10–0 20 The cross-twin analysis of chest breadth and suprasternal height (Table 41) is very different Correlations are essentially *non-existent, only a small within*-individual correlation in monozygotic females has borderline significance There is no evidence here for any relationship of either environ*mental or genetic nature* between chest breadth and suprasternal height or trunk length

The trunk measurements that best provide a measurable genetic component of variability are: sitting height, suprasternal height, waist

width, and chest breadth. While suprasternal height does not provide quite as large ratios as does sitting height, it is an actual measurement of trunk length only, and the results are consistent and highly significant

Waist width gives more satisfactory MZ:DZ ratios than does chest breadth, but it is less easily defined and does not give as descriptive a measure of a trunk dimension as does chest breadth.

LEG AND FOOT MEASUREMENTS

Length

Total leg length (stature minus sitting height)

Since total leg length was obtained by subtracting sitting height from stature, it is related to these two measures, but, so far as intrapair differences are concerned, leg length and sitting height are not simple reciprocal values. In both males and females leg length shows a strong hereditary component of variability (Table 42a) The greater variability in leg length than in trunk length, particularly in males, is in accordance with the observations of D'Arcy Thompson (1952). The male and female IP variances give an F ratio of 12.47, $P<0.005$ The extremely large ♂ DZ.IP F ratio and larger ♂ DZ:MF F ratio than ♀ DZ:MF F ratio are probably indications of a real and rather complex sex difference (Table 42b)

Thigh length (sitting height minus tibial height)

Lower leg length (tibial height)

Thigh length is a good measure of a hereditary component of variability in both males and females. The lower leg is an equally good measure in females, its poorer value in males may be due in part to the greater difficulty in finding tibiale in males because of larger muscle development (Tables 43a and 44a). Both thigh and lower leg lengths show significant sex differences (Tables 43b and 44b).

Foot length (maximal length parallel to axis of foot)

The impressive ME:MZ ratios are primarily a reflection of the accuracy of this measurement, rather than of a large difference between monozygotic twins Foot length appears to have a good hereditary component of variability, though the IP variance is relatively low in males (Table 45a) Like the other length measurements of the leg and foot, foot length shows no sex influenced variation, though a

Table 42a.
Total leg length mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	246		
ME MZ			3 58	< 05
Monozygotic	25	881		
MZ DZ			4 41	> 001
Dizygotic	10	3 883		
DZ IP			64 73	< 001
Interpair	9	251 339		
Female				
Measurement error	21	123		
ME MZ			7 29	< 001
Monozygotic	34	897		
MZ DZ			11 91	< 001
Dizygotic	27	10 679		
DZ IP			1 89	> 05
Interpair	26	20 160		

Table 42b.
Total leg length sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	881		
♂♂ ♀♀			1 02	> 25
Female	34	897		
Dizygotic				
Male	10	3 883		
♂♂ ♀♀			2 75	< 10
Female	27	10 679		
Dizygotic				
Male	10	3 883		
♂♂ ♂♀			10 36	< 001
Unlike sex	16	40 235		
♂♀ ♀♀			3 77	> 001
Female	27	10 679		

strong sex difference is shown by the DZ:MF:DZ comparisons (Table 45b)

Breadth

Ankle breadth (bimalleolar width)

Our data on ankle breadth in males are inconsistent but not significantly so. The extremely small dizygotic variance together with the large monozygotic variance indicate too small a dizygotic variance or a peculiar environmental influence affecting monozygotic males In females ankle breadth shows small total variance but a high hereditary component (Table 46a) (Knee breadth was not taken, as it is quite impossible to standardize this measurement) The large male monozygotic variance gives a significant ♂MZ. ♀MZ F ratio, the ♂DZ ♀DZ ratio is also significant, and a sex difference is indicated only in the ♂DZ MF comparison The results are difficult to interpret, as what appear to be unusual variances occur in both the male monozygotic and female dizygotic samples The ♀IP variance is significantly smaller than that of the ♂ IP. Since this measurement is easily obtained and accurate, it seems improbable that errors in measurement or recording could account for the results (Table 46b).

Heel breadth (maximal)

Foot breadth (maximal)

Table 43a.
Thigh length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	066		
ME MZ			9 89	< 005
Monozygotic	25	653		
MZ DZ			3 42	> 005
Dizygotic	10	2 234		
DZ IP			3 83	< 025
Interpair	9	8 564		
Female				
Measurement error	21	220		
ME MZ			5 25	< 001
Monozygotic	34	1 150		
MZ DZ			3 40	< 001
Dizygotic	27	3 909		
DZ IP			2 20	025
Interpair	26	8 613		

Table 44a.
Lower leg length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	414		
ME MZ			2 21	> 10
Monozygotic	25	913		
MZ DZ			1.56	< 25
Dizygotic	10	1 428		
DZ IP			7.56	> 001
Interpair	9	10 795		
Female				
Measurement error	21	096		
ME MZ			7 97	< 001
Monozygotic	34	765		
MZ DZ			1 83	< 001
Dizygotic	27	3 693		
DZ IP			2 02	< 05
Interpair	26	7 476		

Table 43b.
Thigh length sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	653		
♂♂ ♀♀			1 76	> 25
Female	34	1 150		
Dizygotic				
Male	10	2 234		
♂♂ ♀♀			1 75	> 25
Female	27	3 909		
Dizygotic				
Male	10	2 234		
♂♂ ♂♀			4 34	> 01
Unlike sex	16	9 685		
♂♀ ♀♀			2 48	< 025
Female	27	3 909		

Table 44b
Lower leg length sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	913		
♂♂ ♀♀			1 19	> 25
Female	34	765		
Dizygotic				
Male	10	1 428		
♂♂ ♀♀			2.59	> 10
Female	27	3 693		
Dizygotic				
Male	10	1 428		
♂♂ ♂♀			7 73	> 001
Unlike sex	16	11 034		
♂♀ ♀♀			2 99	> 005
Female	27	3 693		

Table 45a.
Foot length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	011		
ME MZ			13 73	< 001
Monozygotic	24	151		
MZ DZ			6 09	< 001
Dizygotic	10	919		
DZ IP			2 64	< 10
Interpair	9	2 424		
Female				
Measurement error	21	006		
ME MZ			19 33	< 001
Monozygotic	33	116		
MZ DZ			5 51	< 001
Dizygotic	27	639		
DZ IP			3 73	< 001
Interpair	26	2 380		

Table 46a
Ankle breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	003		
ME MZ			35 00	< 001
Monozygotic	25	105		
MZ DZ			49	> 90
Dizygotic	10	051		
DZ IP			49 86	< 001
Interpair	9	2 543		
Female				
Measurement error	21	016		
ME MZ			2 56	< 025
Monozygotic	34	041		
MZ DZ			5 32	< 001
Dizygotic	27	218		
DZ IP			1 43	< 25
Interpair	26	311		

Table 45b
Foot length sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	151		
♂♂ ♀♀			1 30	> 25
Female	33	116		
Dizygotic				
Male	10	919		
♂♂ ♀♀			1 44	> 25
Female	27	639		
Dizygotic				
Male	10	919		
♂♂ ♂♀			3 62	< 025
Unlike sex	16	3 328		
♂♀ ♀♀			5 21	< 001
Female	27	639		

Table 46b
Ankle breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	105		
♂♂ ♀♀			2 56	> 01
Female	34	041		
Dizygotic				
Male	10	051		
♂♂ ♀♀			4 27	025
Female	27	218		
Dizygotic				
Male	10	051		
♂♂ ♂♀			6 41	< 005
Unlike sex	16	327		
♂♀ ♀♀			1 50	< 25
Female	27	218		

Table 47a.
Heel breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	024		
ME MZ			92	> 75
Monozygotic	24	022		
MZ DZ			2 32	< 05
Dizygotic	10	051		
DZ IP			4 59	> 01
Interpair	9	234		
Female				
Measurement error	21	018		
ME MZ			1 00	> 25
Monozygotic	34	018		
MZ DZ			4 22	< 001
Dizygotic	27	076		
DZ IP			3 99	< 001
Interpair	26	303		

Table 48a.
Foot breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	021		
ME MZ			8 86	< 005
Monozygotic	24	186		
MZ DZ			2 04	> 10
Dizygotic	10	380		
DZ IP			5 48	> 01
Interpair	9	2 084		
Female				
Measurement error	21	,015		
ME MZ			11 67	< 001
Monozygotic	34	175		
MZ DZ			.54	> 95
Dizygotic	27	095		
DZ IP			4 11	< 001
Interpair	26	390		

Table 47b
Heel breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	022		
♂♂ ♀♀			1 22	> 25
Female	34	018		
Dizygotic				
Male	10	051		
♂♂ ♀♀			1 49	> 25
Female	27	076		
Dizygotic				
Male	10	051		
♂♂ ♂♀			4 84	< 01
Unlike sex	16	247		
♂♀ ♀♀			3 25	< 005
Female	27	076		

Table 48b.
Foot breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	186		
♂♂ ♀♀			1 06	> 25
Female	34	175		
Dizygotic				
Male	10	380		
♂♂ ♀♀			4 00	> 005
Female	27	095		
Dizygotic				
Male	10	380		
♂♂ ♂♀			1 29	> 25
Unlike sex	16	492		
♂♀ ♀♀			5 18	< 001
Female	27	095		

In females the small variances found in these two measurements are consistent with the findings for ankle breadth While heel breadth is a good genetic character in females, foot breadth does not appear to be so, probably because of strong environmental modification. These two measurements seem to be of little value in males (Tables 47a and 48a) Because of the small ♀ DZ variance, a sex influence is apparent in foot breadth, and, as in ankle breadth, a small IP variance in females differs significantly from that in males While there is a good sex difference in heel breadth, only the ♀ DZ.MF ratio is significant for foot breadth. The findings in these two measurements in general agree with those for ankle breadth (Tables 47b and 48b)

Circumference

Thigh circumference (maximal circumference distal from the gluteal fold)

This is an accurate measurement, showing a predominantly environmental component of variability in both sexes (Table 49a). Although the female variances are larger, as might be anticipated, they are not significantly so A strong sex difference is seen (Table 49b)

Knee minimal proximal circumference (minimal circumference proximal to knee)

Knee minimal distal circumference (minimal circumference distal from knee)

Table 49a

Thigh circumference mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	386		
ME MZ			8 13	< 005
Monozygotic	24	3 139		
MZ DZ			91	> 75
Dizygotic	10	2 857		
DZ IP			3 36	< 05
Interpair	9	9 600		
Female				
Measurement error	21	363		
ME MZ			16 66	< 001
Monozygotic	32	6 048		
MZ DZ			86	90
Dizygotic	27	5 177		
DZ IP			1 71	< 10
Interpair	26	8 872		

Table 49b

Thigh circumference sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	3 139		
♂♂ ♀♀			1 93	> 10
Female	32	6 048		
Dizygotic				
Male	10	2 857		
♂♂ ♀♀			1 81	> 25
Female	27	5 177		
Dizygotic				
Male	10	2 857		
♂♂ ♂♀			5 40	> 005
Unlike sex	16	15 420		
♂♀ ♀♀			2 98	> 005
Female	27	5 177		

These measurements are sufficiently accurate, but are probably of limited value. They may be more meaningful in the female because of greater variability (Tables 50a and 51a) In both these measurements there is a significant sex difference of magnitude approximately equal to that of the thigh circumference The excessive monozygotic variance seen in thigh circumference is absent, particularly in the distal measurement (Tables 50b and 51b).

Calf maximal circumference (maximal circumference of lower leg)

Ankle minimal circumference (minimal circumference of lower leg)

As in the other circumference measurements, the accuracy appears to be good and the environmental component of variability great. Again the variability is larger in females, as is the hereditary component (Tables 52a and 53a). Calf circumference does not provide a particularly good sex difference in the like sex to unlike sex comparison The major sex difference is demonstrated by the relative accuracy of the calf measurements Maximal circumference is easily located in the male because of the molding of the male calf, but in the female the characteristic taper makes it necessary to search for the maximal point. The greater compressibility of the female calf due to subcutaneous fat also probably detracts

Table 50a Knee minimal proximal circumference mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	053		
ME MZ			41.57	< 001
Monozygotic	24	2 203		
MZ DZ			1 05	> 25
Dizygotic	10	2 303		
DZ IP			3 19	05
Interpair	9	7.348		
Female				
Measurement error	21	381		
ME MZ			3 98	< 001
Monozygotic	34	1 517		
MZ DZ			2 20	< 025
Dizygotic	27	3 336		
DZ IP			3 41	> 001
Interpair	26	11 368		

Table 50b. Knee minimal proximal circumference sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	2 203		
♂♂ ♀♀			1 45	> 25
Female	34	1 517		
Dizygotic				
Male	10	2 303		
♂♂ ♀♀			1 45	> 25
Female	27	3 336		
Dizygotic				
Male	10	2 303		
♂♂ ♂♀			3 48	> 025
Unlike sex	16	8 003		
♂♀ ♀♀			2 40	< 025
Female	27	3 336		

Table 51a. Knee minimal distal circumference mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	031		
ME MZ			15 03	< 001
Monozygotic	24	466		
MZ DZ			2 45	< 05
Dizygotic	10	1 140		
DZ IP			2 27	> 10
Interpair	9	2 586		
Female				
Measurement error	21	165		
ME MZ			3 36	< 005
Monozygotic	34	.555		
MZ DZ			1 90	05
Dizygotic	27	1 054		
DZ IP			7 96	< 001
Interpair	26	8 393		

Table 51b Knee minimal distal circumference sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	466		
♂♂ ♀♀			1 19	> 25
Female	34	555		
Dizygotic				
Male	10	1 140		
♂♂ ♀♀			1 08	> 25
Female	27	1 054		
Dizygotic				
Male	10	1 140		
♂♂ ♂♀			3 77	< 025
Unlike sex	16	4 298		
♂♀ ♀♀			4 08	< 001
Female	27	1 054		

from the accuracy Ankle circumference shows a strong sex difference. Whereas the ankle breadth and foot breadth IP variances were significantly greater in the male, the ankle circumference IP variance is significantly greater in the female, further indicating some peculiarity of the ankle and foot variances (Tables 52b and 53b)

Summary of findings on leg and foot

The leg circumference measurements are found to be very accurate, although predominantly subject to environmental modification. This is particularly true of thigh circumference Like pelvic measurements, leg circumferences give somewhat larger MZ·DZ ratios in females than in males Total leg length is the best measurement of genetic variability in this body region, as was total arm length in the first region Thigh length, a derived measurement, appears to be a good measure The fact that tibial height is more difficult to obtain in the male than in the female could easily account for the apparent disparity between the sexes Foot length gives a very satisfactory measure of genetic variability, although foot breadth is subject to severe environmental modification In males, ankle breadth, or bimalleolar breadth, gives surprising results in that the monozygotic variance is

Table 52a Calf maximal circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	007		
ME MZ			166 571	< 001
Monozygotic	24	1 166		
MZ DZ			1 58	< 25
Dizygotic	10	1 840		
DZ IP			4 19	< 025
Interpair	9	7 710		
Female				
Measurement error	21	090		
ME MZ			7 64	< 001
Monozygotic	34	688		
MZ DZ			2 21	< 025
Dizygotic	27	1 520		
DZ IP			7 00	< 001
Interpair	26	10 641		

Table 53a. Ankle minimal circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	031		
ME MZ			5 90	> 01
Monozygotic	24	183		
MZ DZ			1 78	> 10
Dizygotic	10	326		
DZ IP			2 42	< 10
Interpair	9	789		
Female				
Measurement error	21	033		
ME MZ			5 61	< 001
Monozygotic	34	185		
MZ DZ			2 86	< 005
Dizygotic	26	529		
DZ IP			6 71	< 001
Interpair	25	3 550		

Table 52b. Calf maximal circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	1 166		
♂♂ ♀♀			1 69	> 25
Female	34	688		
Dizygotic				
Male	10	1 810		
♂♂ ♀♀			1 21	> 25
Female	27	1 520		
Dizygotic				
Male	10	1 810		
♂♂ ♂♀			2 52	< 10
Unlike sex	16	4 631		
♂♀ ♀♀			3 05	> 005
Female	27	1 520		

Table 53b. Ankle minimal circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	183		
♂♂ ♀♀			1 01	> 25
Female	34	185		
Dizygotic				
Male	10	326		
♂♂ ♀♀			1 62	> 25
Female	26	529		
Dizygotic				
Male	10	326		
♂♂ ♂♀			5 84	< 005
Unlike sex	16	1 903		
♂♀ ♀♀			3 60	> 001
Female	26	.529		

Table 54. Correlation between femoral length and tibial height

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	– 101	> 10
Cross-twin	25	– 028	> 10
Dizygotic			
Individual	10	716	01–02
Cross-twin	10	474	> 10
Female			
Monozygotic			
Individual	34	415	01–02
Cross-twin	34	.543	< 001
Dizygotic			
Individual	27	471	01–02
Cross-twin	27	102	> 10

Table 55. Correlation between tibial height and bimalleolar breadth

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	292	> 10
Cross-twin	25	034	> 10
Dizygotic			
Individual	10	– 086	> 10
Cross-twin	10	– 059	> 10
Female			
Monozygotic			
Individual	34	526	< 001
Cross-twin	34	391	01–02
Dizygotic			
Individual	26	374	05–10
Cross-twin	26	151	> 10

greater than the dizygotic variance; this difference, however, is not statistically significant.

The tibiofemoral index (tibial height to thigh length) gives an MZ:DZ F ratio of only 1.68 in males, and in females a reversal in that the DZ variance is less than the MZ variance, with an F ratio of 1.37. Neither ratio is statistically significant, but it is noteworthy that in females, where both measurements used in the index describe genetic variability, calculation of the index results in a reversal of variance The cross-twin analysis of tibial height and thigh length would appear to confirm the existence of some peculiarity in the relationship of these measurements. The tibiofemoral index suggests that this peculiarity is more marked in females, while the cross-twin analysis points to monozygotic males. The same relationship occurred to some extent in the analysis of forearm length to wrist breadth. Females and dizygotic males show a fairly high within-individual correlation between thigh length and tibial height (Table 54), but no male monozygotic correlation is found Comparison of male monozygotic to male dizygotic within-individual correlations by means of z transformations gives a statistically significant difference, t = 2 31, P = 0 02–0 05

The cross-twin analysis of tibial height and bimalleolar breadth is given in Table 55 No correlation in males is found The female monozygotic individual and cross-twin comparison and the female dizygotic

individual correlations are significant. These significant correlations, together with the low female dizygotic cross-twin correlation, imply some genetic influence upon the covariation of these two dimensions in females, but none in males. In consideration of the male correlations in Tables 54 and 55, it might be hypothesized that there is some environmental influence which affects the lower leg in males, and especially in monozygotic males. The low MZ: DZ ratio for tibial height (Table 44) and the reversal of MZ: DZ male variances for ankle breadth (Table 46), support this hypothesis A similar observation was made concerning the lower arm, and it may well be that some environmental influence affects the distal segments of both extremities; this is more pronounced in the lower limb.

The leg and foot measurements that provide the best measurable genetic component of variability are total leg length and foot length.

HEAD AND NECK MEASUREMENTS

Length

Head length (glabella to opisthocranium)
The larger male MZ variance is not unexpected as this measurement is strongly influenced by the typically male osseous formations in the region of the opisthocranium For the same reason, the maximum measurement is easily obtained in males as the occipital point is usually well defined, but in females it is necessary to search for this point with the caliper. Both the DZ variance and the IP variance would seem to indicate some peculiar environmental factor influencing the male monozygotic variance While comparison of this measurement with head breadth (Table 62a) suggests some interesting hypotheses, the conclusion must be drawn at present that this measurement is of limited value in indicating genetic variability (Table 56a). The larger ♂ MZ than ♂ DZ variance for head length repeats the pattern observed for ankle breadth, which is also largely a bone measurement. A male sex influence upon environmentally influenced variability is suggested by the highly significant ♂ MZ: ♀ MZ ratio. Surprisingly, only a small sex difference is seen in the dizygotic ♂ ♂ : ♂ ♀ : ♀ ♀ ratios (Table 56b)

Head height (tragion to bregma, head in Frankfort plane)
Head height reflects the same type of peculiarity that was observed for head length. The smaller number of

Table 56a.
Head length mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	.009		
ME MZ			60 00	< 001
Monozygotic	25	540		
MZ DZ			44	< 90
Dizygotic	10	236		
DZ IP			1 26	> 25
Interpair	9	297		
Female				
Measurement error	21	013		
ME MZ			7 54	< 001
Monozygotic	34	098		
MZ DZ			2 15	025
Dizygotic	26	211		
DZ IP			3 17	< 005
Interpair	25	669		

Table 56b.
Head length sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	540		
♂♂ ♀♀			5 51	< 005
Female	34	098		
Dizygotic				
Male	10	236		
♂♂ ♀♀			1 12	> 25
Female	26	211		
Dizygotic				
Male	10	236		
♂♂ · ♂♀			2 06	> 10
Unlike sex	16	486		
♂♀ ♀♀			2 30	> 025
Female				

subjects reflects our impression of its limited usefulness We did not take it in the early part of the study, but later we decided that, as this measurement is commonly taken, it should be included (Table 57a) A strong sex difference is seen in the unlike sex comparison (Table 57b)

Total face height (nasion to gnathion)

The male measurement error variance probably reflects the greater difficulty of standardizing this measurement in males rather than a real sex difference The brow and heavier skin on nasion as well as the more massive development of the chin and *overlying tissue contribute to this* problem Nevertheless the possibility of a real sex difference should not be excluded in view of other face height measurements to be considered below In females total face height is a good measure of genetic variability (Table 58a) Absence of a strong sex difference is confirmed by the dizygotic ♂♂ ♂♀ : ♀♀ ratios (Table 58b)

Upper face height (nasion to alveolar point)

Nose height (nasion to nasio-labial angle)

These two measurements provide equally good indications of a hereditary component of variation in males and females (Tables 59a and 60a) Not only is there no sex difference for upper face height and nose height, but with the exception of the

Table 57a
Head height mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	016		
ME MZ			6 56	< 01
Monozygotic	14	105		
MZ DZ			73	> 75
Dizygotic	7	077		
DZ IP			2 88	10
Interpair	6	222		
Female				
Measurement error	13	023		
ME MZ			8 39	< 001
Monozygotic	26	193		
MZ DZ			79	> 75
Dizygotic	22	153		
DZ IP			3 14	005
Interpair	21	480		

Table 58a
Total face height mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	069		
ME MZ			1 52	> 25
Monozygotic	25	105		
MZ DZ			1 81	10
Dizygotic	10	190		
DZ IP			3 11	05
Interpair	9	591		
Female				
Measurement error	21	012		
ME MZ			4 67	< 001
Monozygotic	34	056		
MZ DZ			3 20	> 001
Dizygotic	27	179		
DZ IP			4 40	< 001
Interpair	26	787		

Table 57b.
Head height sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	14	105		
♂♂ ♀♀			1 84	> 25
Female	26	193		
Dizygotic				
Male	7	077		
♂♂ ♀♀			1 99	> 25
Female	22	153		
Dizygotic				
Male	7	077		
♂♂ ♂♀			7 04	< 01
Unlike sex	9	512		
♂♀ ♀♀			3 54	< 01
Female	22	153		

Table 58b.
Total face height sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	105		
♂♂ ♀♀			1 88	< 10
Female	34	056		
Dizygotic				
Male	10	190		
♂♂ ♀♀			1 06	> 25
Female	27	179		
Dizygotic				
Male	10	190		
♂♂ ♂♀			1 85	< 25
Unlike sex	16	351		
♂♀ ♀♀			1 96	> 05
Female	27	179		

Table 59a.
Upper face height mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	031		
ME MZ			1 32	> 25
Monozygotic	24	041		
MZ DZ			3 49	> 005
Dizygotic	10	143		
DZ IP			4 98	01
Interpair	9	712		
Female				
Measurement error	21	016		
ME MZ			1 88	< 10
Monozygotic	34	030		
MZ DZ			3 57	< 001
Dizygotic	27	107		
DZ IP			5 05	< 001
Interpair	26	540		

Table 60a
Nose height mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	009		
ME MZ			3 22	> 05
Monozygotic	24	029		
MZ DZ			4 03	> 001
Dizygotic	10	117		
DZ IP			3 29	< 05
Interpair	9	385		
Female				
Measurement error	21	012		
ME MZ			2 00	05
Monozygotic	34	024		
MZ DZ			3 63	< 001
Dizygotic	27	087		
DZ IP			3 40	> 001
Interpair	26	296		

Table 59b.
Upper face height sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	041		
♂♂ ♀♀			1 37	> 25
Female	34	030		
Dizygotic				
Male	10	143		
♂♂ ♀♀			1 34	> 25
Female	27	107		
Dizygotic				
Male	10	143		
♂♂ ♂♀			61	> 75
Unlike sex	16	087		
♂♀ ♀♀			81	> 75
Female	27	107		

Table 60b
Nose height sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	029		
♂♂ ♀♀			1 21	> 25
Female	34	024		
Dizygotic				
Male	10	117		
♂♂ ♀♀			1 34	> 25
Female	27	087		
Dizygotic				
Male	10	117		
♂♂ ♂♀			88	> 75
Unlike sex	16	103		
♂♀ ♀♀			1 18	> 25
Female	27	087		

MF · ♀ DZ comparison in the latter, the unlike sex variances are actually somewhat smaller than the like sex variances (Tables 59b and 60b)

Ear height (greatest length parallel to axis of ear)

This measurement, though of a soft part, is a good measure of genetic variability in females (Table 61a) Because of the relatively larger female dizygotic variance, no significant difference is found in the comparison with unlike sex pairs (Table 61b)

Breadth

Head breadth (greatest transverse diameter of the vault)

Both sexes, but the male to a greater degree than the female, are found to have a strong hereditary component of variability for this measurement, and a rather low environmentally influenced variability. As both head breadth and head length are compound measurements, and as they measure head size in two different dimensions, the contrast between them is of particular interest. Both males and females appear to have a small environmental and large hereditary variability for head breadth, and a large environmental and small hereditary variability for head length (Table 62a) While for head length the ♂ MZ variance is significantly larger than the female, for head

Table 61a.
Ear height mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	005		
ME MZ			4 60	< 025
Monozygotic	24	023		
MZ DZ			1 70	> 10
Dizygotic	10	039		
DZ IP			8 92	001
Interpair	9	346		
Female				
Measurement error	21	010		
ME MZ			3 10	< 005
Monozygotic	34	031		
MZ DZ			3 13	> 001
Dizygotic	27	097		
DZ IP			2 12	> 025
Interpair	26	206		

Table 61b
Ear height sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	023		
♂♂ ♀♀			1 35	> 25
Female	34	031		
Dizygotic				
Male	10	039		
♂♂ ♀♀			2 49	> 10
Female	27	097		
Dizygotic				
Male	10	039		
♂♂ ♂♀			5 41	005
Unlike sex	16	211		
♂♀ ♀♀			2 18	< 05
Female	27	097		

Table 62a
Head breadth mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	008		
ME MZ			1 13	> 25
Monozygotic	25	009		
MZ DZ			18 22	< 001
Dizygotic	10	164		
DZ IP			5 92	005
Interpair	9	970		
Female				
Measurement error	21	092		
ME MZ			45	975
Monozygotic	34	041		
MZ DZ			4 12	< 001
Dizygotic	27	169		
DZ IP			1 80	< 10
Interpair	26	304		

Table 62b.
Head breadth sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	009		
♂♂ ♀♀			4 56	< 005
Female	34	041		
Dizygotic				
Male	10	164		
♂♂ ♀♀			1 03	> 25
Female	27	169		
Dizygotic				
Male	10	164		
♂♂ ♂♀			2 71	> 05
Unlike sex	16	445		
♂♀ ♀♀			2 63	> 01
Female	27	169		

breadth this is reversed The ♂ IP variance is also significantly larger than the ♀ IP variance for this measurement (P = 0.025) The sex difference for head breadth is comparable to that observed for head length (Table 62b)

Minimal frontal breadth (minimal diameter on temporal crests)
This appears to be a relatively poor measure of genetic or environmental variability in males and of only moderate value in females (Table 63a) The greatest possible usefulness of this measurement would appear to be the measuring of sex difference (Table 63b)

Bizygomatic breadth (maximal diameter on zygomatic arches)
This is a bony measurement showing a particularly weak hereditary component of variability in males, but in females it is a good measure of hereditary variability It somewhat resembles the findings on head length (Table 64a) As in head length, the ♂ MZ variance is significantly larger than the ♀ MZ variance The male and female IP variances are also significantly different (P > 0 01) from each other Bizygomatic breadth, therefore, is a good measure of sex difference (Table 64b).

Bi-ocular width (transverse distance between outer canthi)

Table 63a. Minimal frontal breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	044		
ME MZ			89	> 75
Monozygotic	24	039		
MZ DZ			1 74	> 10
Dizygotic	10	068		
DZ IP			5 60	> 005
Interpair	9	381		
Female				
Measurement error	21	014		
ME MZ			2 86	< 01
Monozygotic	34	040		
MZ DZ			2 23	< 025
Dizygotic	27	089		
DZ IP			2 35	001
Interpair	26	227		

Table 64a. Bizygomatic breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	004		
ME MZ			19 00	< 001
Monozygotic	25	076		
MZ DZ			99	>.75
Dizygotic	10	075		
DZ IP			11 44	< 001
Interpair	9	858		
Female				
Measurement error	21	036		
ME·MZ			94	> 75
Monozygotic	34	034		
MZ DZ			3 12	> 001
Dizygotic	27	106		
DZ IP			2 32	< 025
Interpair	26	246		

Table 63b Minimal frontal breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	039		
♂♂ ♀♀			1 03	> 25
Female	34	040		
Dizygotic				
Male	10	068		
♂♂ ♀♀			1 31	> 25
Female	27	089		
Dizygotic				
Male	10	068		
♂♂ ♂♀			4 06	> 01
Unlike sex	16	276		
♂♀ ♀♀			3 10	005
Female	27	089		

Table 64b Bizygomatic breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	076		
♂♂ ♀♀			2 24	> 025
Female	34	034		
Dizygotic				
Male	10	075		
♂♂ ♀♀			1 41	> 25
Female	27	106		
Dizygotic				
Male	10	075		
♂♂ ♂♀			6 64	< 005
Unlike sex	16	498		
♂♀ ♀♀			4 70	< 001
Female	27	106		

Interocular width (transverse distance between inner canthi)
The accuracy is poor or the environmental influences are great for the relatively small variances obtained in both of these measurements; however, bi-ocular diameter appears to be a more valuable measurement than interocular Once again it appears that the male dizygotic variability is less than would be expected, and in the female sample, the bi-ocular diameter provides a good indication of measurable hereditary influence (Tables 65a and 66a) The sex difference for these measurements is small, and for interocular, as for bizygomatic, the ♂ MZ variance is significantly larger than the ♀ MZ variance (Tables 65b and 66b).

Nose breadth (maximal diameter of alae)
It must be assumed that the male dizygotic variance is biased, and that the small IP variances are the consequence of a small range of alae size in this Caucasian population. In the female sample, however, nose breadth does provide a good indication of measurable hereditary variability (Table 67a) The failure to obtain a significant ratio in the MF: ♀ DZ comparison may indicate a large ♀ DZ variance rather than a small ♂ DZ variance (Table 67b)

Bigonial breadth (maximal distance between external surfaces of gonia)
Accuracy is better and environmental influence is stronger in males for this bony measurement The inheritance factor is good in both sexes, and the female IP variance reflects the smaller range of gonial size in females that would be expected (Table 68a). While bigonial breadth provides a significant sex difference, the unlike sex variance is smaller than could be expected (Table 68b)

Mouth width (maximal diameter between angles of mouth at mucous membrane skin junctions)
The male dizygotics, in mouth width as in other measurements of the soft parts of the head such as ear height and nose breadth, appear to have a low variance In females large F ratios are obtained in spite of a much smaller range of size differences as indicated by the IP values (Table 69a) The ♂ IP variance is significantly greater than the ♀ IP variance ($P < 0.05$) The apparent difference in heritability between the sexes may reflect a real sex difference in view of the DZ·MF DZ ratios (Table 69b)

Neck width (minimal contact diameter above trapezius angle)
The minimal neck width, like the minimal circumference of the wrist, is difficult to find in females because of a gradual taper, but in males pyramiding of the trapezius provides a well defined minimal point. In the

Table 65a.
Bi-ocular width mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	036		
ME MZ			1 34	> 25
Monozygotic	24	041		
MZ DZ			2 39	< 05
Dizygotic	10	098		
DZ IP			2 93	> 05
Interpair	9	287		
Female				
Measurement error	21	054		
ME MZ			72	75
Monozygotic	33	039		
MZ DZ			3 05	< 005
Dizygotic	27	119		
DZ IP			5 72	< 001
Interpair	26	681		

Table 66a
Interocular width mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	003		
ME MZ			8 33	< 005
Monozygotic	24	025		
MZ DZ			1 76	> 10
Dizygotic	10	044		
DZ IP			3 07	05
Interpair	9	135		
Female				
Measurement error	21	008		
ME MZ			1 38	25
Monozygotic	34	011		
MZ DZ			1 91	< 05
Dizygotic	27	021		
DZ IP			5 00	< 001
Interpair	26	105		

Table 65b
Bi-ocular width sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	041		
♂♂ ♀♀			1 05	> 25
Female	33	039		
Dizygotic				
Male	10	098		
♂♂ ♀♀			1 21	> 25
Female	27	119		
Dizygotic				
Male	10	098		
♂♂ ♂♀			1 19	> 25
Unlike sex	16	117		
♂♀ ♀♀			98	> 75
Female	27	119		

Table 66b
Interocular width sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	025		
♂♂ ♀♀			2 27	> 025
Female	34	011		
Dizygotic				
Male	10	044		
♂♂ ♀♀			2 09	> 10
Female	27	021		
Dizygotic				
Male	10	044		
♂♂ ♂♀			1 07	> 25
Unlike sex	16	047		
♂♀ ♀♀			2 24	> 025
Female	27	021		

Table 67a.
Nose breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	004		
ME MZ			4.50	< 025
Monozygotic	24	018		
MZ DZ			1.39	25
Dizygotic	10	025		
DZ IP			3 70	025
Interpair	9	093		
Female				
Measurement error	21	012		
ME MZ			1 25	> 25
Monozygotic	34	015		
MZ DZ			3 47	< 001
Dizygotic	27	052		
DZ IP			1 71	10
Interpair	26	089		

Table 68a
Bigonial breadth mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	014		
ME MZ			3 00	> 05
Monozygotic	25	042		
MZ DZ			3 17	01
Dizygotic	10	133		
DZ IP			6 38	< 005
Interpair	9	849		
Female				
Measurement error	21	027		
ME MZ			1 30	25
Monozygotic	34	035		
MZ DZ			3 97	< 001
Dizygotic	27	139		
DZ IP			2 88	005
Interpair	26	400		

Table 67b.
Nose breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	018		
♂♂ ♀♀			1 20	> 25
Female	34	015		
Dizygotic				
Male	10	025		
♂♂ ♀♀			2 08	> 25
Female	27	052		
Dizygotic				
Male	10	025		
♂♂ ♂♀			3 28	> 025
Unlike sex	16	082		
♂♀ ♀♀			1.58	> 10
Female	27	.052		

Table 68b
Bigonial breadth sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	042		
♂♂ ♀♀			1 20	> 25
Female	34	035		
Dizygotic				
Male	10	133		
♂♂ ♀♀			1 05	> 25
Female	27	139		
Dizygotic				
Male	10	133		
♂♂ ♂♀			2 84	05
Unlike sex	16	378		
♂♀ ♀♀			2 72	> 01
Female	27	139		

Table 69a.
Mouth width mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	025		
ME MZ			1 12	> 25
Monozygotic	23	028		
MZ DZ			1 86	10
Dizygotic	10	052		
DZ IP			6 65	< 005
Interpair	9	346		
Female				
Measurement error	21	007		
ME MZ			3 71	> 001
Monozygotic	34	026		
MZ DZ			2 77	> 005
Dizygotic	27	072		
DZ IP			2 35	< 025
Interpair	26	169		

Table 70a.
Neck width mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	014		
ME MZ			7 07	> 005
Monozygotic	24	099		
MZ DZ			1 71	> 10
Dizygotic	10	169		
DZ IP			3 02	05
Interpair	9	511		
Female				
Measurement error	21	033		
ME MZ			2 42	<.025
Monozygotic	33	080		
MZ DZ			4 63	< 001
Dizygotic	27	370		
DZ IP			2 44	> 01
Interpair	26	902		

Table 69b.
Mouth width sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	23	028		
♂♂ ♀♀			1 08	> 25
Female	34	026		
Dizygotic				
Male	10	052		
♂♂ ♀♀			1 38	> 25
Female	27	072		
Dizygotic				
Male	10	052		
♂♂ ♂♀			3 65	< 025
Unlike sex	16	190		
♂♀ ♀♀			2 64	> 01
Female	27	072		

Table 70b.
Neck width sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	099		
♂♂ ♀♀			1 24	> 25
Female	33	080		
Dizygotic				
Male	10	169		
♂♂ ♀♀			2 19	< 25
Female	27	370		
Dizygotic				
Male	10	169		
♂♂ ♂♀			10 32	< 001
Unlike sex	16	1 744		
♂♀ ♀♀			4 71	< 001
Female	27	370		

Table 71a

Head circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	012		
ME MZ			24 17	< 001
Monozygotic	25	290		
MZ DZ			2 73	< 025
Dizygotic	10	791		
DZ IP			5 27	< 01
Interpair	9	4 167		
Female				
Measurement error	21	025		
ME MZ			6 52	< 001
Monozygotic	34	163		
MZ DZ			3 33	> 001
Dizygotic	27	542		
DZ IP			5 13	< 001
Interpair	26	2 781		

Table 71b.

Head circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	290		
♂♂ ♀♀			1 78	> 25
Female	34	163		
Dizygotic				
Male	10	791		
♂♂ ♀♀			1 46	> 25
Female	27	542		
Dizygotic				
Male	10	791		
♂♂ ♂♀			3 88	< 025
Unlike sex	16	3 069		
♂♀ ♀♀			5 66	< 001
Female	27	.542		

male, neck width appears to be almost entirely environmentally influenced, while in females it is strongly genetic As was suggested in the analysis of wrist breadth, this genetic factor in females might well be associated with taper rather than with actual size (Table 70a) There is a large sex difference for this measurement (Table 70b)

Circumference

Head circumference (maximal occipital frontal circumference above supra-orbital ridges)

This is the best single measurement of head size, combining both head length and head breadth. The present data indicate also that head circumference is a consistent measurement for describing genetic influences in both sexes (Table 71a) There is a large sex difference for this measurement (Table 71b).

Neck circumference (minimal)

The results obtained with this measurement are comparable with those discussed for neck width (see discussion of Table 70a) and they substantiate those conclusions (Table 72a). The male MZ variance is significantly larger than that of the female, indicating a sex as well as an environmental influence. The sex difference *for this measurement is extremely* large. (Table 72b).

Table 72a.
Neck circumference mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	484		
ME MZ			2 15	> 10
Monozygotic	24	1 038		
MZ DZ			1 20	> 25
Dizygotic	10	1 244		
DZ IP			3 89	< 025
Interpair	9	4 837		
Female				
Measurement error	21	557		
ME MZ			61	90
Monozygotic	34	341		
MZ DZ			4 98	< 001
Dizygotic	27	1 698		
DZ IP			2 57	01
Interpair	26	4 368		

Table 72b.
Neck circumference sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	1 038		
♂♂ ♀♀			3 04	> 005
Female	34	341		
Dizygotic				
Male	10	1 244		
♂♂ ♀♀			1 36	> 25
Female	27	1 698		
Dizygotic				
Male	10	1 244		
♂♂ · ♂♀			12 47	< 001
Unlike sex	16	15 518		
♂♀ · ♀♀			9 14	< 001
Female	27	1 698		

Summary of findings on head and neck

The head and neck measurements clearly differ in many respects from the measurements of the post-cranial regions This accords with the observations of Howells (1949, 1951), and may be anticipated on the basis of evolutionary evidence (Washburn, 1951) In this region, unlike the rest of the body, the genetic component of variability is more marked for measurements other than those taken parallel with the long axis of the body

Head length is found to be a remarkably poor measure of genetic variability, considering its prominence in anthropological studies Because of the results we obtained for head length, the cephalic index (head breadth to head length) is of particular interest. This index (Table 73) provides the largest MZ:DZ ratio of all indices calculated on our data. Highly significant ratios are obtained in both males and females. Although head length measurements give an actual reversal of the MZ and DZ variances in males, the MZ:DZ ratio for the cephalic index is 9 90 The cross-twin analysis of head length and head breadth (Table 74) further complicates interpretation of this phenomenon The correlations are reversed by both sex and zygosity. Peculiarities in these measurements were found in Boas' data (Fisher and

Table 73. Head breadth to head length mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Monozygotic	24	1 108		
MZ DZ			9 90	< 001
Dizygotic	10	10 973		
DZ IP			1 89	< 25
Interpair	9	20 694		
Female				
Monozygotic	34	3 232		
MZ DZ			3 30	< 001
Dizygotic	27	10 650		
DZ IP			1 23	> 25
Interpair	26	13 138		

Table 74 Correlation between head breadth and head length

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	055	> 10
Cross-twin	25	024	> 10
Dizygotic			
Individual	10	651	02- 05
Cross-twin	10	365	> 10
Female			
Monozygotic			
Individual	34	470	001- 005
Cross-twin	34	356	02- 05
Dizygotic			
Individual	27	099	> 10
Cross-twin	27	171	> 10

Gray, 1925), and while our data suggest some complex biological relationship in these head dimensions, no explanation is possible at present Head length is taken from two points which undergo osseous development at puberty in the male. The male monozygotic intrapair variance is larger than the male dizygotic intrapair variance for bizygomatic and interocular breadths, which again measure bone development. The head circumference results are probably attributable to a genetic component of variability in head size This measurement more than any other describes head size, irrespective of the shape or proportions of the cranium

The measurements of the head and neck which appear to provide the best measurable genetic component of variability are head breadth, upper face height, nose height, bigonial breadth, and head circumference.

CONCLUSIONS DRAWN FROM ANTHROPOMETRY

Measurements differ markedly in their practical value for genetic studies of morphological variation. In each body region certain measurements provide consistent and relatively good measurable genetic variability, while other measurements appear to have greatest value in studies of environmental effects, sex differences, and sex influenced variability.

Measurements of girth or circumference, as well as surface contact measurements, which have been largely neglected in anthropometry, merit inclusion among the more useful measurements In general, however, measurements taken parallel with the longitudinal axis of the body show the strongest genetic component of variability This finding is in accordance with those in previous genetic studies of morphological measurements (Pearson, 1903; Davenport, 1925; Howells, 1949) In males, 28% of the measurements taken parallel with the body's longitudinal axis provide values of P = 0 001 in the MZ.-DZ comparison, while only 7% of the other measurements provide similar probability values. In females this is true for 60% of the length measurements, and only 21% of other measurements. In the three post-cranial body regions, total arm length, sitting height, suprasternal height, and total leg length provide the best measures of genetic variability. The cross-twin correlation between total arm length and suprasternal height (Table 75), and that between suprasternal height and total leg length (Table 76) yield moderate but statistically significant coefficients within individuals and for the monozygotic cross-twin comparisons. The covariation between these measurements is no more strongly influenced by factors within the individual than by factors which commonly affect both members of a monozygotic twin pair. The dizygotic cross-twin correlations further imply that the influences which similarly affect these measurements are strongly genetic

Application of a cross-twin analysis to anthropometry has in many instances contributed to an understanding of the complex interrelations of different measurements. However, the value of this analysis is somewhat limited in small samples with variables in which few significant comparisons between *z* values can be obtained. All compound measurements such as these are fairly strongly influenced by environmental factors and the correlations between measurements even within the same individual are only moderate. In addition, some familial correlations are to be anticipated in dizygotic cross-twin comparisons. In spite of these limitations, certain striking features have been demonstrated by the cross-twin analysis

The monozygotic within-individual and the monozygotic cross-twin correlations are remarkably similar in every instance. This is true whether or not there is a marked difference either between the sexes or in the monozygotic and dizygotic individual correlations. Any influences that similarly affect the interrelations of two dimensions within a monozygotic twin individual affect also these two dimensions in the co-twin in a like manner. This can probably be

Table 75 Correlation between total arm length and suprasternal height

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	497	01–02
Cross twin	25	445	02–05
Dizygotic			
Individual	10	726	01–02
Cross-twin	10	213	> 10
Female			
Monozygotic			
Individual	32	688	< 001
Cross-twin	32	666	< 001
Dizygotic			
Individual	27	498	005–01
Cross-twin	27	384	02–05

Table 76. Correlation between suprasternal height and total leg length

	n	*r*	*P*
Male			
Monozygotic			
Individual	25	407	02–05
Cross-twin	25	499	01–02
Dizygotic			
Individual	10	487	> 10
Cross-twin	10	403	> 10
Female			
Monozygotic			
Individual	32	600	< 001
Cross-twin	32	521	001–005
Dizygotic			
Individual	27	392	02–05
Cross-twin	27	136	> 10

interpreted as indicating a genetically conditioned response A second feature to be seen in this analysis is that, so long as length measurements are correlated with length measurements and breadth measurements with breadth measurements, the cross-twin analysis is internally consistent, and the dizygotic cross-twin correlations are the lowest The only exception to this is in the correlation of thigh length and tibial height, where the male monozygotics have the lowest correlation, but presumably the lower leg constitutes a special case in males, at least in our data By contrast, whenever comparisons are made between length and breadth measurements, the internal consistency of the analysis is upset with tremendously complex sex and zygosity differences

In view of the results of the cross-twin analysis, it is not surprising to find that the calculation of indices grossly oversimplifies the biological relationship between any two measurements. The brachial index fails to provide a significant test of genetic variability though both measurements employed in its calculation are found to have a strong genetic component of variability, and the cross-twin analysis indicates that their interrelationship is genetically influenced The cephalic index, on the other hand, provides a highly significant test of genetic variability, although one of the measurements employed in its calculation (head length) varies

more between the two members of monozygotic twin pairs than between the two members of dizygotic twin pairs. Furthermore, the cross-twin analysis shows that there were strong environmental and sex influences affecting the covariation of head length and head breadth Conflicting findings appear also in the ratio of tibial height to thigh length The female monozygotic intrapair variance exceeds that of dizygotic twins, and though the male monozygotic intrapair variance is not significantly less than the dizygotic intrapair variance, it does not present the reversal seen in females It was in females that the variance of the separate measurements, thigh length and tibial height, showed highly significant genetic variability, and the cross-twin analysis substantiates these results The male MZ.DZ ratio for tibial height was not statistically significant, and thigh length and tibial height were negatively correlated. In no instance is an index consistent with the other findings Anthropometric indices, such as the ponderal index, do not warrant a genetic interpretation until we possess a better understanding of the biological interrelations between body segments

Other twin studies have found a genetic component of variability in the majority of anthropometric indices (Newman et al, 1937; Clark, 1956). However, in these studies it was in all probability the inheritance factor in growth rate and pattern of development which imparted the measurable genetic component of variability, since the subjects used were in the period of rapid growth and development As the development of secondary sex characteristics had not been completed, the sex differences observed in the present study were not found by either Newman or Clark

Other sex differences, or patterns of differences, which can be seen in the present data may suggest potential avenues of investigation with more extensive data. In all six measurements in which the female monozygotic intrapair variances are larger than the male monozygotic intrapair variances, the female dizygotic intrapair variances are smaller than the male dizygotic intrapair variances. A similar and converse relationship holds for 20 measurements in which the male monozygotic intrapair variances are larger than the female monozygotic intrapair variances Another type of sex pattern is exemplified by stature The male dizygotic intrapair variance is smaller than the female dizygotic intrapair variance, while the male dizygotic interpair variance is considerably larger than that of the female There is an almost universal sex difference in adaptation, whether in health or disease, and morphological variances would ap-

pear to follow similar patterns which tend always to run in opposite or compensatory directions.

For each body region measurements have been selected which gave the strongest and most consistent indications of genetic variability. Many other measurements may be of equal or even greater interest for certain types of studies In studies of hereditary-environmental interactions, it is important to have measurements which will significantly reveal both genetic and environmental influences At times it may be desirable to work with only one type of variability Again, sex influenced variability (one sex showing greater genetic or en*vironmentally influenced variability* than the other) may be of interest Sex differences, and attributes which show no sex differences, are both of value

In Table 77 we have classified the measurements used in this analysis which provide statistically significant measurable variability those which measure both genetic and environmentally influenced variability, those which measure only genetic influences, those which measure only environmental influences, those which measure sex influenced variability, and those which measure sex differences Significance has been taken as $P < 0.025$

Table 77. Evaluation of anthropometric measurements

	Genetic and environmental		Genetic only		Environmental only		Sex influence		Sex difference	
	♂	♀	♂	♀	♂	♀	MZ	DZ	♂	♀
Table Measurement										
10 Stature	x	x							x	x
11 Weight					x	x			x	x
Arm & Hand										
14 Total arm lg	x	x							x	x
15 Upper arm lg		x	x						x	x
16 Forearm lg			x	x					x	x
17 Hand lg			x			x	x		x	x
18 Mid-finger lg		x	x							x
19 Wrist bd	x	x							x	
20 Hand bd									x	x
21 Upper arm circ					x	x			x	x
22 Forearm circ		x					x	x	x	x
23 Wrist circ				x	x				x	x
Trunk										
26 Sitting height		x	x						x	x
27 Sittg suprastl		x	x							x
28 Bideltoid					x	x			x	x
29 Bi-acromion						x			x	x
30 Chest bd		x							x	x
31 Chest dpth					x	x				x
32 Waist wd	x	x						x		x
33 Hip bd		x			x				x	
34 Bi-iliac		x								
35 Bitroch					x	x			x	x
36 Chest circ	x					x				
37 Chest circ						x			x	x
38 Waist circ		x			x				x	x
39 Hip circ.		x			x					

Table 77. Evaluation of anthropometric measurements (Continued)

	Genetic and environmental		Genetic only		Environmental only		Sex influence		Sex difference	
	♂	♀	♂	♀	♂	♀	MZ	DZ	♂	♀
Leg & Foot										
42 Total leg lg		x	x						x	x
43 Thigh lg	x	x							x	x
44 Lower leg lg		x							x	x
45 Foot lg	x	x							x	x
46 Ankle bd		x			x		x	x	x	
47 Heel bd				x					x	x
48 Foot bd					x	x		x		x
49 Thigh circ					x	x			x	x
50 Knee prox		x			x				x	x
51 Knee dist					x	x			x	x
52 Calf circ		x			x					x
53 Ankle circ		x			x				x	x
Head & Neck										
56 Head lg		x			x		x			x
57 Head ht					x	x			x	x
58 Total face ht		x								
59 Upper face ht			x	x						
60 Nose ht			x	x						
61 Ear ht		x			x				x	
62 Head ht			x	x			x			x
63 Min frontal		x							x	x
64 Bizygomatic				x	x		x		x	x
65 Bi-ocular				x						
66 Interocular					x		x			x
67 Nose bd				x	x				x	
68 Bigonial			x	x						x
69 Mouth wd		x							x	x
70 Neck wd		x			x				x	x
71 Head circ	x	x							x	x
72 Neck circ				x			x		x	x

Chapter XI

Fat, Bone, and Muscle

The physical measurement of the body's composition in terms of fat, bone, and muscle has great value in physiological and nutritional studies. Measurement of these three variables is extremely difficult, and a number of methods have been employed with various success: roentgenogrammetric, densimetric, and anthropometric.[1] While all of these methods have contributed to a basic understanding of body composition, only anthropometric methods are at present practical for large scale studies (Brozek, 1956).

FAT MEASUREMENTS

Body fat is the variable which is most directly related to nutritional status and physiological change and which in adults shows the greatest fluctuations. The anthropometric technique for measuring body fat is by the measurement of skinfold or subcutaneous fat (Edwards, 1950; Brozek, 1956). While there are many complex factors associated with the accumulation of subcutaneous fat in different individuals, at different ages, and under different environmental

[1] A Committee on Nutritional Anthropometry was established in 1951 under the Food and Nutrition Board of the National Research Council.

conditions, genetic influences also may be suspected of playing a role in the accumulation of fat and in its patterning For this reason we made subcutaneous fat measurements to determine whether genetic variability could be detected by a twin analysis employing an anthropometric technique

To measure skinfold thickness, a pair of skinfold calipers was obtained from Dr. Ancel Keys of the University of Minnesota. The instrument employed was a spring-loaded caliper equipped with jaws having an area of 28 27 square millimeters which exerted a pressure of approximately 10 grams per square millimeter. This instrument, an early version of those now in use, was calibrated in inches, and readings were made to the nearest thirty-second of an inch. The same instrument was employed throughout the course of the study, and all measurements were made by the same anthropometrist. Five sites on the right side of the body were used: upper arm, chest, scapula, abdomen, and thigh. The results were as follows

Upper arm skinfold thickness (posterior surface, midway between the acromial and olecranon processes)

This skinfold measurement had good repeatability, particularly in males In females the measurement was less accurate, due to both the greater relative thickness and the nature of the fold itself In males, upper arm fat appears to be largely environmentally influenced, as indicated by both the ME·MZ and DZ IP ratios (Table 78a) In females a fairly good genetic component of variability is observed The comparison of like sex and unlike sex dizygotic twins indicates strong sex differences at this site (Table 78b).

Chest skinfold thickness (right axillary border, above pectoralis major, at approximately the level of the first rib)

The particular site of this measurement was selected in an effort to obtain comparable results in males and females. The poor repeatability in males reflects the difficulty frequently encountered in raising a skinfold at this site There is little to recommend this measurement as it was made in the present study (Tables 79a and 79b)

Scapular skinfold thickness (immediately below the inferior border of the right scapula)

This is a reasonably repeatable measurement, with an apparently strong genetic component of variability in females The male monozygotic intrapair variance is relatively large, significantly larger, in fact, than the intrapair variance of the female monozygotic twins The male interpair variance is small in comparison

Table 78a. Upper arm skinfold thickness mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	571		
ME MZ			18 77	< 001
Monozygotic	25	10 720		
MZ DZ			1 24	> 25
Dizygotic	10	13 250		
DZ IP			9 46	< 001
Interpair	9	125 337		
Female				
Measurement error	18	2 528		
ME MZ			4 24	001
Monozygotic	32	10 719		
MZ DZ			2 28	< 025
Dizygotic	27	24 407		
DZ IP			2 58	01
Interpair	26	62 865		

Table 79a Chest skinfold thickness mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	1 857		
ME MZ			2 55	10
Monozygotic	25	4 729		
MZ DZ			21	< 99
Dizygotic	10	1 000		
DZ IP			3 09	05
Interpair	9	3 089		
Female				
Measurement error	18	250		
ME MZ			5 38	<.001
Monozygotic	32	1 344		
MZ DZ			1 54	> 10
Dizygotic	27	2 074		
DZ IP			1 88	> 05
Interpair	26	3 899		

Table 78b. Upper arm skinfold thickness sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	10 720		
♂♂ ♀♀			1 00	> 25
Female	32	10 719		
Dizygotic				
Male	10	13 250		
♂♂ ♀♀			1 84	< 25
Female	27	24 407		
Dizygotic				
Male	10	13 250		
♂♂ ♂♀			5 14	< 01
Unlike sex	13	68 077		
♂♀ ♀♀			2 79	> 01
Female	27	24 407		

Table 79b Chest skinfold thickness sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	4 729		
♂♂ ♀♀			3 52	< 005
Female	32	1 344		
Dizygotic				
Male	10	1 000		
♂♂ ♀♀			2 07	> 10
Female	27	2 074		
Dizygotic				
Male	10	1 000		
♂♂ ♂♀			2 92	05
Unlike sex	13	2 923		
♂♀ ♀♀			1 41	< 25
Female	27	2 074		

Table 80a. Scapular skinfold thickness mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	1 643		
ME MZ			15 03	< 001
Monozygotic	25	24 700		
MZ DZ			1 15	> 25
Dizygotic	10	28 400		
DZ IP			1 44	> 25
Interpair	9	41 022		
Female				
Measurement error	18	1 083		
ME MZ			4 33	< 001
Monozygotic	32	4 688		
MZ DZ			4 61	< 001
Dizygotic	27	21 611		
DZ IP			3 44	> 001
Interpair	26	74 385		

Table 80b Scapular skinfold thickness sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	24 700		
♂♂ ♀♀			5 27	< 005
Female	32	4 688		
Dizygotic				
Male	10	28 400		
♂♂ ♀♀			1 31	> 25
Female	27	21 611		
Dizygotic				
Male	10	28 400		
♂♂ ♂♀			1 04	> 25
Unlike sex	13	29 577		
♂♀ ♀♀			1 37	25
Female	27	21 611		

with that for females, but no significant sex difference is found in the comparison of like sex to unlike sex dizygotic twins (Tables 80a and 80b)

Abdominal skinfold thickness (midway between umbilicus and iliac crest)
The striking difference in repeatability between males and females for this measurement is unquestionably due to the difficulty frequently encountered in raising a good skinfold in females because of an extensive and relatively firm umbilical fat pad From this standpoint, a fold above the iliac crest would have been preferable. This difficulty may account also for the large sex difference in the comparison of like sex to unlike sex dizygotic twins The ME MZ and DZ IP ratios indicate that the variability in abdominal fat is greatly influenced by environment (Tables 81a and 81b)

Thigh skinfold thickness (anterior surface, immediately proximal to the patella)
The lesser accuracy in females relative to males is the result of the firm nature of the thigh fat typical of females, which frequently makes it extremely difficult to obtain a fold for measurement In males this skinfold appears to give a good measurable genetic component of variability, whereas in females environmental influences must be considered relatively more important A significant sex difference is found (Tables 82a and 82b).

Table 81a. Abdominal skinfold thickness mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	857		
ME MZ			29 76	< 001
Monozygotic	25	25 500		
MZ DZ			1 48	< 25
Dizygotic	10	37 600		
DZ IP			6 76	< 005
Interpair	9	254 222		
Female				
Measurement error	18	7 528		
ME MZ			3 05	< 01
Monozygotic	32	22 984		
MZ DZ			1 52	> 10
Dizygotic	26	34 904		
DZ IP			4 90	< 001
Interpair	25	171 081		

Table 82a. Thigh skinfold thickness mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Measurement error	7	1 000		
ME MZ			12 30	> 001
Monozygotic	25	12 300		
MZ DZ			3 06	> 01
Dizygotic	10	37 650		
DZ IP			5 54	> 005
Interpair	9	208 491		
Female				
Measurement error	18	3 000		
ME MZ			13 64	< 001
Monozygotic	32	40 922		
MZ DZ			1 61	.10
Dizygotic	27	65 907		
DZ IP			1 15	> 25
Interpair	26	75 899		

Table 81b Abdominal skinfold thickness sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	25 500		
♂♂ ♀♀			1 11	> 25
Female	32	22 984		
Dizygotic				
Male	10	37 600		
♂♂ ♀♀			1 08	> 25
Female	26	34 904		
Dizygotic				
Male	10	37 600		
♂♂ ♂♀			3 30	> 025
Unlike sex	13	123 923		
♂♀ ♀♀			3 55	< 005
Female	26	34 904		

Table 82b. Thigh skinfold thickness sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	25	12 300		
♂♂ ♀♀			3 33	> 005
Female	32	40 922		
Dizygotic				
Male	10	37 650		
♂♂ ♀♀			1 75	<.25
Female	27	65 907		
Dizygotic				
Male	10	37 650		
♂♂ ♂♀			4 48	> 01
Unlike sex	11	168 769		
♂♀ ♀♀			2 56	< 025
Female	27	65 907		

Summary of findings on body fat measurements

The demonstration of complex differences between the sites measured is in accordance with previous observation (Edwards, 1951; Garn, 1954, 1956, Brozek, 1956) The frequent sex differences in the nature of the fat at different sites previously commented upon (Garn and Harper, 1955) were substantiated by our observations on the comparative repeatability of these measurements in males and females The present data indicate that the variability of the different fat deposits is influenced by sex, heredity, and environment Of principal interest here, however, is the fact that skinfold thickness can provide a significant measure of genetic variability

The sites which provide such measurable genetic variability differ for males and females. In males the best measurement is obtained on the thigh, and in females the scapular fold It is possible that these results in part reflect the male tendency to accumulate upper body fat with weight gain, and the female tendency to accumulate thigh fat with weight gain With such environmentally influenced variables as skinfold thickness, genetic differences are less easily measured in the regions most strongly influenced by environment Without question, environmental influences predominate in the present data at the chief site of fat deposition, the abdomen

The variation in fat accumulation at different sites in the presence of weight change has been pointed out by Garn (1954) and by others Since the absolute thickness rankings of the fat at different sites change with weight gain, the intercorrelations between these sites must change also A cross-twin analysis of the different fat sites would then require an arrangement of twin pairs in accordance with weight differences as well as by sex and zygosity Consequently, the present data are inadequate to permit interpretation of this type of analysis

BONE MEASUREMENTS

The measurement of bone size by anthropometric methods requires a site which provides two good contact points for the caliper with a minimum of overlying soft tissue Preferably this should be a measurement of breadth or width. Wrist breadth or bistyloid breadth (Tables 19a and 19b) fulfills these requirements admirably In the analysis of anthropometric measurements, wrist breadth was found to give an extremely good measure of a genetic component of variability in both males and females

MUSCLE MEASUREMENTS

Measurements of muscle are not as readily obtained as are those of fat and bone. One measure of muscle or muscularity which has been proposed, however, has shown considerable promise for certain purposes (Brozek, 1956) While this measurement (upper arm diameter) includes bone as well as muscle, it can be considered predominantly a measure of muscle mass The circumference of the upper arm is taken midway between the acromial process and the olecranon, and corrected for the subcutaneous fat thickness measured at the same point In the present study, upper arm circumference (Table 21a) and upper arm skinfold (Table 78a) were obtained in a manner suitable for this measurement of muscle mass. As the skinfold caliper was calibrated in inches, conversion to centimeters was necessary The formula employed in analysis was that given by Brozek (1956)· ($D = C/\pi - S$), where D equals arm diameter, C equals upper arm circumference, and S equals skinfold thickness

Upper arm diameter ($D = C/\pi - S$) Comparable MZ:DZ and DZ:IP ratios in both males and females indicate a significant measure of genetic variability. No sex influenced variability is found and there is a large sex difference as demonstrated by the like to unlike sex dizygotic twin comparison (Tables 83a and 83b).

Table 83a.
Upper arm diameter mean variances

	n	Variance	F ratio	P
Male				
Measurement error	7	023		
ME MZ			2 43	> 10
Monozygotic	23	056		
MZ DZ			3 14	> 01
Dizygotic	10	176		
DZ IP			3 64	> 025
Interpair	9	641		
Female				
Measurement error	18	021		
ME MZ			3 43	< 005
Monozygotic	32	072		
MZ DZ			2 14	025
Dizygotic	27	154		
DZ IP			2 52	01
Interpair	26	388		

Table 83b.
Upper arm diameter sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	23	056		
♂♂ ♀♀			1 29	> 25
Female	32	072		
Dizygotic				
Male	10	176		
♂♂ ♀♀			1 14	> 25
Female	27	154		
Dizygotic				
Male	10	176		
♂♂ ♂♀			7 91	> 001
Unlike sex	13	1 392		
♂♀ ♀♀			9 04	< 001
Female	27	154		

CONCLUSIONS DRAWN FROM FAT, BONE, AND MUSCLE STUDIES

Without question, upper arm diameter, which is predominantly a measurement of muscle mass, provides an extremely satisfactory indication of a genetic component of variability. Furthermore, this is an objective measurement of muscle which does not depend upon subjective evaluation on some relative scale. Wrist breadth was found to provide an equally good measure of genetic variability in bone size It was similarly possible to demonstrate genetic variability in subcutaneous fat or skinfold thickness in both males and females by employing two different measurement sites In females the subscapular fold and in males the fold on the anterior surface of the thigh proximal to the patella provided highly significant differences between the mean intrapair variances of monozygotic and dizygotic twins

CHAPTER XII

The Analysis of a Body-Build Taxonomy

Man's natural curiosity about himself and about the manner in which one differs from another, together with his recognition of some relationship between body structure and function, have led to the development of many different body-build taxonomies (Kretschmer, 1921, Bean, 1926; Penda, 1928, Sheldon, 1940, Lindegard, 1953) Formerly physique was classified into "types" based on the assumption that there was discontinuity in the variation of body form associated with different physiological and functional characteristics. More recently the continuous nature of variation in body form has been recognized, and the classification systems now in use attempt to represent a continuum of variation in terms of body components (Tanner, 1953).

The most widely used of these classification systems is that of the somatotype, which by its author's definition is a description of continuous morphological variation (Sheldon, 1954) This system was therefore suggested for a genetic study of morphological variation, and it was used in the first analysis of the present data.[1] Although the analysis of somatotype employed control data instead of interpair variances as in the analysis of the morphological measurements, the original method as well as its interpretation have been retained

[1] The body-build analysis utilized the first 100 twin pairs studied (Osborne, 1956)

Body-build typologies have most commonly described three major variants or components of physique. Kretschmer's term for the first variant is pyknic, meaning compact, for the second, musculare, meaning athletic; and for the third, asthenic, meaning weak. Bean also had three variants short and round; medium, bulky, or massive; and tall, wiry, and narrow He termed these three types respectively hypomorph, mesomorph, and hypermorph Sheldon's corresponding terms in the somatotype classification are endomorphy, mesomorphy, and ectomorphy.

Sheldon (1940) describes the characteristics of these three components and their essential features in the extremes of each type. Endomorphs are round and soft individuals with small bones and low body density, the limbs are tapering and short relative to the trunk; there is a predominance of the abdominal viscera and of the proximal segments of the arms and legs over the distal segments, the anterior-posterior and lateral diameters of the body are equal. Mesomorphs are massive, solid individuals with large bones, big joints, and heavy muscles; the thoracic cage predominates over the abdominal region, and both the proximal and distal segments of the arms and legs are large, the transverse diameters exceed the anterior-posterior diameters. Ectomorphs are linear, fragile individuals in whom body surface predominates over the mass, the bones are small and delicate, but unlike those of endomorphs, the distal segments of the arms and legs are relatively long, the anterior-posterior diameters are extremely reduced, and the lateral diameters much less so These descriptions define the extremes of the three types and an individual is rated for each of these three components on a scale of 1–7 in terms of his expression of each component relative to the extremes found in the population. Each individual is given a rating His type, therefore, is represented by three numerals designating his place along the total range of variation for endomorphy, mesomorphy, and ectomorphy

Somatotyping as it is presently employed is an anthroposcopic technique, which utilizes, in addition to the purely visual evaluations of body form and character, the ponderal index and weight history of the subject (Sheldon, 1954) Tanner (1954) reported the most recent check upon the reliability of the somatotype ratings in terms of observer and measurement error [2] In this check a test was made of self-consistency, as well as the reliability among the ratings of three trained individuals Tanner found an average standard error of measurement of 0 33 units, though the error was consistently a little

[2] Measurement error comparable to that used in the analysis of anthropometric measurements was not obtained for somatotype in our study

lower for ectomorphy, about 0.28, slightly higher for endomorphy, and the highest of all for mesomorphy, about 0 36 The average standard error between two total somatotype ratings will therefore fall somewhere between 0.5 and 1.0 somatotype units.

It has previously been pointed out that in the present twin study each individual twin was given a study number taken at random, and that the diagnosis of zygosity was maintained separately until all evaluations had been completed The data required for somatotyping was placed upon 5 x 8 cards, an example of which is reproduced in Appendix III-A The somatotype photographs, together with the data cards, were divided into two stacks so that in no instance were the co-twins placed in the same stack. To these twin subjects were added a number of non-twin individuals who were photographed and repeatedly measured concurrently with the study of the twin subjects as a check upon the error in anthropometric measurements The somatotype ratings utilized in this study were then made by Dr William Sheldon. The time required for completing the initial evaluations of the somatotypes meant that in addition to the randomized numbers and separation of the members of a twin pair, two or more days elapsed before the second member of any twin pair was rated Under Dr. Sheldon's standard procedure initial ratings are gone over a second or third time to correct chance errors in the evaluations, but, to assure extreme objectivity in our study, more than the usual care was given to the initial rating, and only these initial ratings were used in the analysis

In the analysis of ratings such as these it is desirable to have some evaluation of the differences which could be expected to occur between unrelated individuals For this purpose Dr Sheldon made available some of his college material for use as an unrelated control. While a college population is not entirely comparable with the population from which the twin sample was drawn, it provided in this case readily accessible data with two distinct advantages: first, a college population is usually in good physical health; second, it is a somewhat selected population with a more homogenous socio-economic background than almost any other young adult population and therefore less variable. This means that the variances of this population should tend toward the minimal rather than the maximal, and should therefore constitute a more rigorous control for the dizygotic variance values.

We selected one male series from an urban coeducational college and one female series from an urban coeducational college comparable in socio-economic level with the popu-

lation from which the twins were drawn. Similar male and female private college series also were used. The age, race, height, weight, and somatotype ratings were recorded for approximately 1200 males and 1500 females from these college series. The twin pairs in the present study could be classified with only two or three exceptions into two racial categories: Jews and Northwest European non-Jews Accordingly, the college series were separated into the same two classes Only individuals over 18 years of age were included. Application of these criteria resulted in a control series of 1008 females, 805 of whom were classified as Northwestern European and 203 as Jews, and a control series of 657 males, 543 of whom were Northwestern European, and 114 Jews. Since analysis of the somatotype data by age showed almost no difference in the means and variances at the different age levels, combining the age groups was possible. There were some small differences in weight by age and also by race; because of possible pertinence to the weight data of this study, as well as its anthropological interest, this information is presented in Appendix III-B.

The somatotype ratings were made on a half point scale and the analysis of intrapair variances was the same as that employed with the measurement data. The intrapair difference in total somatotype is the sum of the intrapair differences in endomorphy, mesomorphy, and ectomorphy without regard to sign. If Twin A was rated 3 4^2 3 and Twin B (co-twin) rated 3^2 4 2, the intrapair differences would be ½, ½, 1; thus the intrapair difference in the total somatotype would be tabulated: ½ + ½ + 1 = 2 The calculation of intrapair variances for the control group, which was done to provide a comparison of the degree to which co-twins are more alike than individuals drawn at random from a comparable population, was based upon sample variance If many unrelated individuals were formed into pairs at random, their intrapair variance would be $(\Sigma x^2/2n)$. Since this is an estimate of the variance in the control population, the control sample variance, s^2, a simpler estimate, was calculated instead

Endomorphy

The monozygotic and dizygotic intrapair variances are essentially equivalent in males and females, and fail to provide significant F ratios. In the control population the estimated intrapair variances are significantly larger than the mean dizygotic intrapair variances Comparison of like and unlike sex dizygotic twins indicates a highly significant sex difference for endomorphy. Endomorphy appears primarily to describe sex differences (Tables 84a and 84b).

Mesomorphy

The results obtained for mesomorphy are similar to those for endomorphy. Again in the unrelated control group, significant ratios are obtained, but mesomorphy appears primarily to describe sex differences (Tables 85a and 85b)

Ectomorphy

Ectomorphy, at least in females, shows a genetic component of variability in the MZ : DZ comparison. Sex differences are less pronounced than in endomorphy and mesomorphy, and there is a suggestion that the male dizygotic mean intrapair variance may be abnormally low If male and female data are combined, an F ratio of 3 76 is obtained which gives P<0 001 (Tables 86a and 86b).

Total somatotype

Mean intrapair variances for total somatotype could not be estimated for the control by the present methods. Total somatotype results are similar to those of ectomorphy, from which it apparently derives most of the genetic component of variability If male and female data are combined, the F ratio is 2.34, P<0.001 Sex differences in total somatotype are strongly indicated. Presumably they are contributed by the endomorphy and mesomorphy components (Tables 87a and 87b)

Table 84a.
Endomorphy mean variances

	n	*Variance*	*F ratio*	*P*
Male				
Monozygotic	24	18		
MZ DZ			1 80	> 10
Dizygotic	8	33		
DZ C			3 96	< 025
Control	657	1 30		
Female				
Monozygotic	31	15		
MZ DZ			1 80	> 05
Dizygotic	24	27		
DZ C			2 58	< 005
Control	1008	70		

Table 84b.
Endomorphy sex comparison

	n	*Variance*	*F ratio*	*P*
Monozygotic				
Male	24	18		
♂♂ ♀♀			1 23	> 25
Female	31	15		
Dizygotic				
Male	8	33		
♂♂ ♀♀			1 21	> 25
Female	24	27		
Dizygotic				
Male	8	33		
♂♂ ♂♀			3 82	< 05
Unlike sex	10	1,26		
♂♀ ♀♀			4 67	001
Female	24	27		

Table 85a.
Mesomorphy mean variances

	n	Variance	F ratio	P
Male				
Monozygotic	24	18		
MZ DZ			1 46	< 25
Dizygotic	8	27		
DZ C			6 19	< 005
Control	657	1 65		
Female				
Monozygotic	31	19		
MZ DZ			1 35	< 25
Dizygotic	24	25		
DZ C			2 31	> 005
Control	1008	58		

Table 86a.
Ectomorphy mean variances

	n	Variance	F ratio	P
Male				
Monozygotic	24	09		
MZ DZ			1 24	> 25
Dizygotic	8	11		
DZ C			17 09	< 001
Control	657	1 86		
Female				
Monozygotic	31	13		
MZ DZ			3 92	< 001
Dizygotic	24	51		
DZ C			1 92	025
Control	1008	98		

Table 85b.
Mesomorphy sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	18		
♂♂ ♀♀			1 02	> 25
Female	31	19		
Dizygotic				
Male	8	27		
♂♂ ♀♀			1 06	> 25
Female	24	25		
Dizygotic				
Male	8	27		
♂♂ ♂♀			5 70	> 01
Unlike sex	10	1 54		
♂♀ ♀♀			6 16	< 001
Female	24	25		

Table 86b
Ectomorphy sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	09		
♂♂ ♀♀			1 40	< 25
Female	31	13		
Dizygotic				
Male	8	11		
♂♂ ♀♀			4 68	> 01
Female	24	51		
Dizygotic				
Male	8	11		
♂♂ ♂♀			5 91	< 01
Unlike sex	10	65		
♂♀ ♀♀			1 27	> 25
Female	24	51		

Table 87a.
Total somatotype mean variances

	n	Variance	F ratio	P
Male				
Monozygotic	24	94		
MZ DZ			1 57	< 25
Dizygotic	8	1 48		
Female				
Monozygotic	31	97		
MZ DZ			2 56	< 01
Dizygotic	24	2 48		

Table 87b.
Total somatotype sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	24	94		
♂♂ ♀♀			1 03	> 25
Female	31	97		
Dizygotic				
Male	8	1 48		
♂♂ ♀♀			1 68	25
Female	24	2 48		
Dizygotic				
Male	8	1 48		
♂♂ ♂♀			5 58	> 01
Unlike sex	10	8 26		
♂♀ ♀♀			3 33	< 01
Female	24	2 48		

CONCLUSIONS DRAWN FROM SOMATOTYPE STUDIES

The nature of the somatotype classification system to a considerable extent opposes endomorphy and ectomorphy. Hooton's modification of this system (Hooton, 1951, Dupertuis and Emanuel, 1956) is constructed upon the premise that there is a strong inverse relationship between endomorphy and ectomorphy, ectomorphy being primarily the absence of endomorphy Howells (1952), in applying factorial analysis to a selected group of men, concluded that there is an inverse relationship between endomorphy and ectomorphy To test this interrelationship in the present data, one member of each twin pair was taken randomly and multiple regressions were calculated following Mather (1947) for the regression of actual values of endomorphy and mesomorphy upon the actual values of ectomorphy. These calculations were made separately for monozygotic males and females, and for dizygotic males and females. Significant regressions were found for endomorphy upon ectomorphy in three of the four categories of twins Only in the dizygotic females was the regression coefficient insignificant. The indication is certainly strong that in the present data endomorphy and ectomorphy cannot be considered

independent variables The only question of importance to our study, however, is whether the interrelationship of endomorphy and ectomorphy affects the intrapair difference values of these two components

To test the possible effect of the endomorphy-ectomorphy relations upon intrapair differences, multiple regressions have been calculated for the regression of the intrapair differences of endomorphy and mesomorphy upon the intrapair differences of ectomorphy. Again these regressions were calculated separately for monozygotic males and females, and for dizygotic males and females No statistically significant regressions were found Apparently the regression of endomorphy upon ectomorphy is not sufficiently strong to be reflected in the relatively small intrapair differences between the two members of a twin pair.

In a concordance-discordance test of body build, von Verschuer (1950) reported no discordance in monozygotic twins His classification used three body types which described only the extremes of body build, and there is no way of judging what constitutes concordance. In a concordance-discordance test of somatotype ratings, in which concordance was exact agreement in the three somatotype components, 5 pairs of monozygotic twins were found to be concordant and 50 pairs discordant; no dizygotic pairs were concordant and therefore all 32 pairs were discordant Fisher's Exact Chi-square test of significance gives $P = 0.09$

In employing somatotype ratings for correlations with disease or physiological functions, some of the different numerical ratings frequently are combined. Sheldon (1954) described 88 different numerical combinations or somatotypes, which he said could be grouped into 19 "somatotype families" (Sheldon, 1940). Since a somatotype family may include, for example, such somatotypes as 7 2 1 and 5 4 3, described as mesomorphic endomorphs, the criteria for concordance are greatly extended. In a concordance-discordance test of these groupings, a significant difference between monozygotic and dizygotic twins was not found (Osborne, 1956) In this test zygosity diagnosis was based solely on sex and the blood groups With the use of additional criteria for diagnosing zygosity, six pairs of twins previously classified as monozygotic were reclassified as dizygotic Five of these six pairs were discordant for the 19 somatotype groupings With this zygosity diagnosis 29 pairs of monozygotic and 8 pairs of dizygotic twins were concordant, while 26 pairs of monozygotic and 24 pairs of dizygotic twins were discordant. An Exact Chi-square calculation gives a probability level of 0.01. If a 95% confidence interval is calculated by the cross ratio method (Wolff, 1956, Haldane, 1956), confidence limits of

1 28–8 73 are obtained for an observed ratio of 3 35.

In the present analysis, though the values of the three components can be shown to have some genetic validity when used as a description of a continuous range of variability (Table 87a), their particular combinations can not be shown to have a genetic basis. However, in a concordance-discordance test, a very small difference in somatotype rating could be sufficient to classify the pair as discordant, and when gross groups of somatotypes are used, significant differences between monozygotic and dizygotic twins are obtained

The relation between endomorphy and ectomorphy is statistically significant for the actual values in these components, but this relation did not significantly affect the intrapair difference values for the two components The numerical representation of body build as given by the total somatotype rating shows evidence of genetic control as well as of a strong factor of sex influence The genetic aspect of the somatotype rests primarily upon the ectomorphic component, and the sex-influenced factor is disclosed largely by endomorphy and mesomorphy.

Chapter XIII

A Masculinity and Femininity Rating

No feature of morphological variation is more obvious than that of sexual dimorphism. Males differ from females not only gonadally and in respect to primary sex characters, but also in a whole array of secondary sex characteristics which relate to male or female adaptation, possibly to disease susceptibility, and to practically every aspect of the individual's interaction with his environment The quantitative nature of man's sexual dimorphism, a matter of common observation, also is of considerable biological interest.

Innumerable anthropological and medical studies have attempted to describe variations in secondary sex characteristics for possible correlations with disease, and with physiological differences between and within the two sexes These descriptions of morphological bisexuality have in general been carried out either parallel with, or in place of, a body build classification In the preceding analysis of one body-build taxonomy, we concluded that a large part of the variability which was described involved secondary sex differences. Because of this finding, and the possible genetic nature of much of the variation observed in secondary sex characteristics, we decided to carry out an analysis of the relative masculinity and femininity within each sex as a part of the present study of morphological variation We discovered, however, that there was no single classification system in use which

would be both appropriate for the present analysis and comparable for the two sexes. Therefore, it became necessary to establish our own descriptive system, based upon the methods and observational criteria of various authors.[1] The masculinity-femininity rating which we employed was developed before the analysis of the anthropometric measurements was made. No photographs or measurement data on the twin and control subjects of this study were used in the development of this masculinity-femininity rating system.

DEVELOPMENT OF A MASCULINITY-FEMINITY RATING SCALE

Important considerations in setting up a rating scale of classified secondary sex differences are the nature of the differences to be encountered, what kind of criteria can be used, and how the criteria can be arranged in a meaningful order. The most striking feature in all classifications of sex differences is the opposition of upper body to lower body development, following the same divisions of the body that were discussed by Washburn (1951) based upon evolutionary evidence arms and trunk, pelvis and legs, and head and neck. The male pattern is a relatively greater development of the upper part of the body, while the female pattern is greater development of the lower part of the body. Following upper and lower body dominance comes the male's angularity versus the smooth curves of the female, muscle versus fat on the upper arm and thigh, angularity versus taper of the distal segments, body flatness versus body roundness, and the relatively greater development of fat above or below the anatomical waist. Sex differences in the third region, head and neck, which are less easily defined, are generally excluded from the various classifications of secondary sex characteristics and will not be included here.

To arrange criteria for the purpose of classification, the major divisions should be upper body and lower body, with the various subdivisions listed in an orderly fashion. Secondary sex characteristics and their sex differences can be classified and described as follows

Upper body (above the pelvic brim)

Upper extremity

In the male the arm is longer in relation to both the trunk and the lower

[1] Bayer, 1939, 1940, Bayley and Bayer, 1946, Bullen and Hardy, 1946, Draper 1925, 1941, Jones, 1942, Lockhart, 1943, Seltzer, 1943, 1945, Tanner, 1953, Wolff, E., 1933, Wolff, G., and Steggerda, 1943

extremity than in the female When viewed laterally the male arm is straight in profile whereas the female arm tends toward hyperextension at the elbow. Hyperextension is occasionally seen in an obviously masculine arm, but it is associated with an extremely well developed triceps In front or back view the male arm hangs from the shoulder, whereas in the female there is a carrying angle and the curve of the shoulder extends smoothly over the shoulder point and along the side of the arm. The female arm is cylindrical with a tapered forearm, whereas the male upper arm is flattened laterally and the forearm exhibits proximal bowing, with angularity rather than taper.

Trunk

In the male the thorax, or upper trunk, is long in proportion to the abdomen or lower trunk. There is an obvious dominance of the thorax over the abdomen. In the female, even in the absence of obesity, the abdomen dominates by its relatively large surface area The sternum is shorter in the female, often giving the neck the appearance of great length The female thorax is rounder and the rib cage is constricted, whereas in the male the thorax appears to be square due to the greater lateral diameter in proportion to the anterior-posterior diameter. The male chest appears to be flattened in the lateral view.

Waist

In the female the waist appears to be and actually is relatively high because of the shortness of the thorax relative to the abdomen. The waistline is typically well-defined in the female and often is constricted or marked by a deep depression The lateral aspect of the rib-cage is nearly perpendicular to the waistline, while the supra-iliac fat pad or iliac crest forms a sharp angle to the vertical The lower angle is definitely sharper than the upper angle. In the male the actual point of the minimal waist circumference is poorly defined, and the angle formed at the waistline by the lateral rib-cage is sharper or more abrupt than that formed by the iliac crest. The fat roll, when present, appears above the point of attachment of Poupart's ligament in the male, it is the fat of the flank or upper abdomen In the female the fat, actually on the iliac crest, is continuous with the fat of the lower abdomen and also with that of the buttocks

Abdomen

In the male the abdominal musculature should be evident with a well defined Poupart's ligament forming a sharper angle at the pubic symphysis than in the female, where a horizontal line, the "line of Venus," is often found above the mons pubis In the female a second line may be present, Holden's line; this is the line of

flexure of the hip joint, and it is associated with the presence of fat on the anterior part of the thigh Even in the relatively obese male some evidence of strong abdominal musculature is evident, and the center of fat accumulation is above the umbilicus. Only in males of low masculinity in this region is a pronounced fat accumulation below the umbilicus seen with a "line of Venus" demarcating a pubic fat pad In the female the umbilicus is the center of fat accumulation, and therefore often appears as a pit There is protuberance of the abdomen below the umbilicus in the female, and, in the relatively obese, the pubic pad is clearly defined between the "line of Venus" and the flexure, or Holden's line, which runs to the depression seen on anterior or posterior view between the trochanteric pad and the iliac fat pad In the female there is a relatively large anterior-posterior diameter along a line drawn through the lower abdomen and the buttock.

Lower body (below the pelvic brim)

Buttocks

The typical female buttocks dominate the lower body in posterior view, and, in the extremely feminine form, may appear to dominate the physique The gluteal groove is well developed, and there is no iliac furrow; the fat of the buttocks is continuous with the fat of the flank, so that the buttocks appear to extend continuously from the fold, or line of Nates, to the waistline, which is then clearly differentiated from the subscapular area, often by a depression. In the male the fat of the flank and that of the buttocks are separated by the iliac furrow. In the typical male buttock there is dimpling marking the lateral aspect of the gluteus maximus. The conformation of the male buttocks is square or rectangular, whereas in the female it is rounded in contour, lacking angularity. The sacral triangle is usually visible in both sexes and the posterior superior iliac spines are clearly marked by dimples The point of the isosceles triangle is formed by the gluteal groove In the female this triangle is shorter and broader than in the male, as is characteristic of the sacrum

Trochanteric fat pad and hip line

In the female a sub-trochanteric fat pad is present even in the relatively lean The centering of the pad below the trochanter gives the greatest hip breadth at this point in females, unless large iliac pads are present In the male the greatest breadth is at the head of the trochanter. In the female the subtrochanteric pad together with the iliac fold form the double curve of the female hipline, with the narrow point falling approximately at the

trochanter and lateral point of the skin crease (Holden's line) on the front of the thigh. In the typical male a double curve may appear also, but it is formed by the head of the trochanter and the iliac crest, and the narrow point lies well above the trochanter. In the female, the trochanteric pad is often fused with the fat of the buttock and the front of the thigh, and there is a rather abrupt lower margin. In lean females and those of low femininity, and occasionally in lean males of low masculinity, the trochanteric pad may appear completely delineated because of the relative absence of fat on the front of the thigh and side of the buttock.

Thigh

In the female there is often a thick fat covering on the front of the thigh concealing the musculature and giving rise to a skin crease, Holden's line Even in the lean, however, the contour is smooth and the patella is small. In the male the thigh appears to extend without demarcation to Poupart's ligament, and the patella is large and prominent with some definition above. In the female the thighs are often approximated above the knees and the knees are in contact. The thigh has a funnel or cone shape in the female, whereas in the male it is more cylindrical with some angularity at the knee. In massively muscled males the thighs may approximate, but the knees are generally bowed, not in contact, and the demarcation of musculature is evident In very thin females the thighs may be widely separated, but then they are concave on the inner surface due to the absence of strong adductor and vastus medialis muscles, and the thighs angle inward at the knees The knees may approximate even in very lean females

Lower leg

The lower leg of the male has unevenness or angularity, while in the female even a well developed calf is smoothly curved and tapering. These characteristics are particularly true of the inner surface In the calf of the typical male, the inner curve of the gastrocnemius is prominent and well defined The outer surface curves relatively sharply toward the external malleolus In the male the malleoli are large and clearly seen, adding to the appearance of angularity, while even in the lean female the malleoli are small and the calf tapers to the ankle

Method of quantification

Following the description of the most readily observed secondary sex characteristics is the problem of rating or quantifying the relative development of these characteristics in each sex.

Past experience in the classification of physique has clearly shown that definable standards must be established if assigned ratings are to be repeatable. The number of categories to be recorded in any classification of continuous or quantitative variation is entirely arbitrary, though there are certain practical considerations It is both logical and convenient to have a midpoint and a middle category in the range of variation which will approximate the most commonly occurring expression of a specific attribute in the majority of "normal" populations If the attributes are genetic, or have any meaning in terms of biological adaptation, each population will have its characteristic midpoint, and consequently it is superfluous to try to establish an exact midpoint for general application The curve of distribution also will differ, and the essential problem is to establish criteria which will describe the extremes at approximately equal distance from the midpoint for each of the different attributes employed as classificatory criteria. Such a range is implicit in the classification of sexual variation by the terms· hypo-, average, and hypermasculine or feminine. In view of the number of rateable criteria and the range of variation observed, it seemed to us reasonable to use also intermediate categories between the extremes and the midpoint The large number of attributes to be rated further indicated the need for an actual scoring system, rather than just arbitrary categories. Five categories seemed particularly convenient for this purpose, each to have a range of 20 points on a total scale of 100 points with a midpoint of 50.

Table 88 presents our method of scoring, utilizing the classification of secondary sex characteristics described above Class I is hypomasculine or hypofeminine, and Class V is hypermasculine or feminine. Upper body and lower body are scored separately by the four sets of criteria listed under each region. If an individual is in Class III (at the middle of the range of variability) in each of the four sets of criteria in the upper body, the total upper body score is 100, and the average score for each of the four sets of criteria is 25. If the same ratings hold for the lower body, the total lower body score also is 100, which, divided by four, again gives an average score of 25 By adding these two averages, we get a masculinity-femininity rating of 50, the midpoint of the scoring scale. (The adjustment of score for shoulder-hip ratio will be discussed presently.)

From a practical standpoint, the most difficult problem is the assignment of point scores. For this purpose both visual examples and word descriptions have been employed (Appendix IV) Few, if any, individuals can be precisely matched, even for

Table 88. Masculinity—femininity rating scale

Example			A		B		C		D		
Class		I		II		III		IV		V	
Point Score		5		15		25		35		45	
Rating	0	10	20	30	40	50	60	70	80	90	100

Upper body (above pelvic brim)

- Upper extremity — Point score
- Trunk — Point score
- Waist — Point score
- Abdomen — Point score

Total point score /4 =

In male, adjustment for shoulder-hip ratio = ______

Upper body score = ______

Lower body (below pelvic brim)

- Buttock — Point score
- Trochanteric pad & hip line — Point score
- Thigh — Point score
- Lower leg — Point score

Total point score /4 =

In female, adjustment for shoulder-hip ratio = ______

Lower body score = ______

Masculinity-femininity rating = ______

one criterion, and decisions as to an individual's place on the scale of distribution can be made much more easily by comparison than by matching; that is, by determining whether an individual scores higher than a second but lower than a third for each criterion For this reason the visual examples A, B, C, and D in Figures 1 and 2 (inside back cover) illustrate the midpoints between classes, and the intervening classes are verbally described for each criterion Few individuals will be encountered who fall nicely into the same class for all criteria, therefore it was necessary to construct composites from actual photographic examples

In scoring the four sets of criteria in the two body regions, no actual comparison of upper and lower body development is achieved As the relative development of these two regions constitutes the most universally rec-

ognized secondary sex difference, correction of the masculinity-femininity rating for this criterion was deemed advisable. While relatively broad shoulders are a masculine characteristic, certain problems are encountered in determining a meaningful shoulder-hip ratio The male pelvis is frequently quite broad at the crest of the ilium, where iliac breadth is customarily measured This is due often to massive bony development of the iliac crest, which adds breadth but certainly is not feminine The position of the subject in the photograph also makes it extremely difficult to obtain a reliable measurement, or even an impression of shoulder breadth. The best compromise which could be devised was to lay straightedges parallel to the body's long axis from the axillary apexes in the posterior view. Hip breadth was taken as the greatest width, whether at the trochanter or iliac crest In this way masculine males were not unduly penalized for prominent iliac crests relative to males low in masculinity having indiscernible iliac crests and prominent trochanteric pads Similarly, in females the more feminine received full credit for large development of their trochanteric pads. Table 89 presents the scoring method The increments apply to 5" x 7" photographs with a magnification factor of 0 059. If the male score is applied to the upper body, and the female score to the lower body, a single criterion of upper or lower body dominance may be used

Table 89 Secondary scoring scale: shoulder-hip ratio

Male shoulder-hip ratio applied to upper body	
Shoulders less than hip breadth by 1 mm or more	= minus 10 points
Shoulders approximately the same or wider than hip breadth by less than 2 mm	= no score
Shoulders wider than hip breadth by 2 mm or more	= plus 10 points
Female shoulder-hip ratio applied to lower body	
Hips less than shoulder breadth by 1 mm or more	= minus 10 points
Hips approximately same or wider than shoulder breadth by 2 mm	= no score
Hips wider than shoulder breadth by 2 mm or more	= plus 10 points

APPLICATION OF THE MASCULINITY-FEMININITY RATING SCALE

The purpose of a twin analysis of the masculinity-femininity rating is to determine whether these ratings describe a genetic component of variability in morphological bisexuality. As in the analysis of anthropometry, subjecting the repeatability of the rating to test as an inherent part of the analysis is of the greatest importance. Extreme care was taken to guard against any bias in ratings All photographs were identified by random numbers, and those of the two members of every twin pair were separated into different stacks for independent scoring Photographs of the measurement experiment individuals and all other photographs available were interspersed with the photographs of the twin subjects in the first stack. Scores for each evaluated element were then assigned to every individual in the first stack, but the scores were not totaled until the entire series had been completed. Following the scoring of the first member of each twin pair, the measurement experiment photographs were interspersed with the twin photographs of the second stack and the procedure was repeated to obtain independent values The twin pairs were then matched and intrapair differences between total scores were calculated Measurement error variances between the first and second ratings on the measurement experiment individuals were calculated. The twin pairs were then classified in accordance with the previous diagnosis of zygosity, and the data were analyzed in a manner comparable with that employed with the anthropometric measurements

The results of the analysis are presented in Tables 90a and 90b In both males and females the mean dizygotic intrapair differences are found to be significantly larger, $P<.001$, than the mean monozygotic intrapair differences In males there is a significant difference between the measurement error variance and the monozygotic intrapair variance, whereas in females this difference is not statistically significant Quite obviously this sex difference is due more to the relative size of the monozygotic intrapair variance in males and females than to a difference in accuracy of ratings for the two sexes It may reflect an actually greater difference between male monozygotic twins in characteristics of a sexual nature, as could be implied from the analysis of anthropometric measurements which indicated that for certain measurements the mean monozygotic intrapair variance exceeded that of the mean dizygotic intrapair differences

In neither males nor females are significant differences found between the dizygotic intrapair and interpair

Table 90a. Masculinity—femininity rating mean variances

	n	Variance	F ratio	P
Male				
Measurement error	17	7 169		
ME MZ			3 78	< 005
Monozygotic	25	27 125		
MZ DZ			4 64	< 001
Dizygotic	10	125 938		
DZ IP			1 96	< 25
Interpair	9	216 840		
Female				
Measurement error	25	10 375		
ME MZ			1 78	< 10
Monozygotic	34	18 474		
MZ DZ			6 72	< 001
Dizygotic	27	124 190		
DZ IP			1 13	> 25
Interpair	26	140 874		

Table 90b. Masculinity—femininity rating sex comparison

	n	Variance	F ratio	P
Monozygotic				
Male	25	27 125		
♂♂ ♀♀			1 47	> 25
Female	34	18 474		
Dizygotic				
Male	10	125 938		
♂♂ ♀♀			1 01	> 25
Female	27	124 190		
Dizygotic				
Male	10	125 938		
♂♂ ♂♀			1 03	>.25
Unlike sex	16	130 078		
♂♀ ♀♀			1 05	> 25
Female	27	124 190		

variances For males the score range is 17.5 to 67 5, and in females the range is 35 0 to 72 5 Since it does not appear that any serious lack of variability was present in this population, this finding may indicate a possibility that a relatively small number of genetic factors have an androgenic or gynecogenic effect upon morphological characteristics

CONCLUSIONS DRAWN FROM MASCULINITY-FEMININITY RATING

Thus our masculinity-femininity rating scale makes it possible by a twin analysis to demonstrate statistically a genetic component of variability for morphological bisexuality. The strength of this component of variability appears to exceed that demonstrated for a body-build taxonomy, and it is comparable with those found for many single anthropometric measurements and for the measurements of fat, bone, and muscle.

Part Five

Summary and Conclusions

Chapter XIV

Summary and Conclusions

Genetic studies of man may be purely theoretical, such as evolutionary studies, or they may be descriptive, based upon observational data, as, for example, studies of gene frequencies in different populations; or they may be conducted with a view to the application of genetic knowledge to human problems, as may be the case in medical genetics Irrespective of the nature of the genetic study, it is necessary to recognize the importance of multifactorial and complex inheritance, that which is based upon more than one pair of genetic determinants and involves genetic and environmental interactions to bring about a given character (the phenotype) It is necessary also to distinguish between cause and effect, between genotype and phenotype. The genotype can be inferred only by observation of the phenotype, while the phenotype results from the interaction of heredity and environment Elucidation of the heredity-environment interaction with respect to complexly inherited traits is therefore vital to the future development of human genetics In spite of many difficulties, such as those of health problems peculiar to twins, and accurate diagnosis of zygosity, twins provide the best subjects available for the study of genetic-environmental interactions Twins are of particular value in the study of complexly inherited variation where simple Mendelian segregations cannot be observed.

In the use of the twin method for the study of heredity-environment interactions, certain principles are more

important than some standardized procedures One of these is "total ascertainment," the study of all available cases rather than a sample chosen because of convenience of collection The purpose of "total ascertainment" is to avoid unconscious bias, but collection of all available twins will not in itself achieve this, in fact, for certain problems it may actually result in unconscious biases of a very serious nature. However convenient it would be to use stereotyped methods, the design of a particular study and the procedures to be employed must accord with the nature of the problem and the results sought

The restriction of the twin study method by convention has all too frequently resulted in failure to ask the most appropriate questions of a given body of twin data, and has without doubt hindered the development of the method for attacking many problems of genetic-environmental interactions In general, the twin method has been confined to studies with the limited concept of "degree of heritability," which has little meaning in human problems, since heritability is by nature relative and human populations are characterized by genetic and environmental heterogeneity. The initial question to be asked for human genetic problems is whether a hereditary component of variability can be measured by the twin method and the techniques employed. The primary purpose of the present twin analysis has been to examine different measures or evaluations of "normal" morphological variation in order to find statistically measurable components of variability Such an evaluation can then provide the foundation for developing more elaborate genetic methods for studying these easily recognizable "normal" morphological characteristics and their relation to function in both health and disease.

For the study of any specific problem, it is necessary to obtain appropriate subjects, and this requires some type of selection As the present study was to be of normal morphological variation, the most necessary criterion for the selection of subjects was health status, determined by complete laboratory and medical work-up. As the purpose of the investigation was to test for a genetic component in trait variability rather than to determine growth rates or patterns of development, only subjects over 18 years of age, past the period of most rapid growth and development, were studied To avoid extreme genetic heterogeneity in the sample, only Caucasians were included; the extremes of environmental influences in a large metropolitan area were avoided by drawing subjects from the low middle to upper middle income group Volunteer subjects were taken as they came, without intentional selection on the basis of either sex or zygosity; in this way, the criterion of health status was allowed to operate

as the principal selective factor. Thus the most important bias to which twin data may be subject was equalized for the different twin categories While volunteer participation unquestionably was influenced by social and psychological factors which were related to sex and zygosity, no effect of these factors could be demonstrated upon the intrapair differences of the twin pairs studied, so far as the morphological characteristics under investigation were concerned.

In drawing conclusions from the analysis of intrapair differences, one must remember that the magnitude of these differences is of an entirely different order from that encountered in other types of data, such as those from studies of unrelated individuals or different racial groups. The average coefficient of genetic relationship between dizygotic twins is one-half, and the majority of genetic studies have shown that the average of phenotypic correlations between individuals in this degree of relationship also is one-half Similarly, the environmental influences affecting the two members of a twin pair, or even those affecting different pairs in good health and drawn from the same socio-economic level of an urban population, must differ much less than they would in studies of urban and rural groups, those in high and low economic brackets, or groups with various diseases. A twin analysis is comparatively exacting, and measurements which fail to describe significant differences in twins may still be of value for describing genetic and environmental influences in other types of studies The measurement differences found in our study characterize this specific twin sample, these differences are proportional to the magnitude of the genetic and environmental components of variability in this twin population only.

The analyses of ponderal index (*height* $\sqrt[3]{weight}$) and of different anthropometric indices clearly show that such ratios of body dimensions are gross over-simplifications of the biological relations they purport to describe While it is possible that these indices may be useful for specific problems, they are of extremely limited value for genetic studies The cross-twin analysis as employed here was helpful in the interpretation of these indices, though its usefulness was somewhat limited by the lack of high within-individual and monozygotic twin correlations between different measurements The correlations between different anthropometric measurements are only moderate, and, in our limited sample, provided few significant differences Certain facts emerged, however, which are of interest in the interpretation of genetically conditioned morphological variability Length and breadth dimensions appear to be relatively independent; this could be seen from both the variances and cross-twin analyses.

Other investigators have reported similar findings; they have also reported the relatively greater genetic component of variability, which we observed, for post-cranial measurements taken parallel with the long axis of the body

Perhaps the most interesting result of the cross-twin analysis is the suggestion that whatever the influences may be that affect the relations between two measurements in a monozygotic twin, these influences have a similar effect between the two members of the twin pair This implies genetically determined relations of the segments of the body involved, and indicates that the response to the prenatal and developmental environment to which the two members of a monozygotic twin pair are subjected is genetically conditioned, insofar as these influences affect body proportions. While the existence of such a relation might be considered self-evident, the fact that it can be demonstrated statistically may have considerable importance for studies of genetic-environmental interactions, and for epidemiological studies employing co-twin control methods.

Birth weight and body weight in growing children can be shown to have a measurable genetic component of variability, but in our data adult weight cannot. Variability in stature is strongly influenced by genetic factors, but the ponderal index poorly describes a genetic component of variability for the relations of stature and weight. With the use of the ponderal index, however, a suggestion of a genetic component for gross size, or height-weight proportionality, is found Before a more definitive analysis can be carried out, it is necessary to have some practical measure or description of either body volume or body mass (the relations of size and form).

We have found a limited and therefore a manageable number of anthropometric measurements (Table 77) which statistically measure a genetic component of variability with impressive accuracy and good reliability These findings are in contrast to those in studies of growing children, in which practically all measurements give significant differences between the mean intrapair differences of monozygotic and those of dizygotic twins, due, presumably, to the facts that most body proportions are undergoing growth changes, and growth rates and patterns of development are largely genetic. In our study, in which male and female data have been analyzed separately, significant sex differences in variability are found; some measurements provide significant measures of genetic variability in males but not in females, and vice versa This kind of sex difference has been previously recognized; Pearson pointed it out as early as 1903

Variations in fat, bone, and muscle are of interest for many medical and

physiological studies. Simple anthropometric instruments, utilizing readily accessible body sites, provide accurate measurements of all three, and all show a significant genetic component of variability.

In the analysis of a taxonomy of body build (the somatotype), evidence of genetic variability is obtained from a simple numerical representation of the continuous range of difference in the three components of body build described Specific combinations of these components or types were not found to have a genetic basis, though gross combinations of different somatotypes differ significantly between monozygotic and dizygotic twin pairs The genetic component of this typology appears to rest primarily upon the aspect which essentially describes relative linearity. This finding is compatible with the results from anthropometric measurements. It should be noted that in constitutional studies of disease susceptibility or resistance, relative linearity of physique has generally been found to give the most promising correlations When such correlations are noted, the diseases in question are those which on other evidence also have shown familial or hereditary tendencies, and frequently sex incidence differences as well, such as coronary heart disease, tuberculosis, peptic ulcer, diabetes, and gallstones (Draper, Dupertuis, and Caughey, 1944).

Because of the genetic importance of sex and sex differences, and the range of variability which normally occurs in secondary sex characteristics, a quantitative system for describing this variable was developed for the present analysis. A simple and highly repeatable rating system was devised for describing morphological bisexuality in both males and females. This masculinity-femininity rating indicates a genetic component of variability in both sexes as effectively as do many of the better anthropometric measurements

We have shown that certain simple, easily obtained, and objective measurements of body segments, of fat, bone, and muscle, and of linearity, and the morphological expression of bisexuality, have statistically measurable genetic components of variability in adult twins in general good health These morphological variables constitute the phenotypic expressions of complex or multifactorial inheritance suitable for studies of genetic-environmental interactions, and, since they seem fully representative of a large part of man's genetically conditioned variability, they can be used in developing methods appropriate for working with the more complex part of human inheritance. While family or sibling data will be required for understanding the genetic mechanisms in the inheritance of complex variables, such as are exemplified by these morphologi-

cal measurements, possibilities exist for further application of twin study techniques

Co-twin control methods can be used to further our understanding of genetic-environmental interactions through the investigation of different associations between measured differences in morphological and physiological variables in both health and disease The present study has suggested also that comparative data for twins at different age levels would be of value in genetic studies of growth processes With the development of appropriate statistical methods, it should also be possible by the purposeful selection of twin and family data effectively to partition different components of variance, and even to take advantage of some of the biases to which twin data are frequently susceptible. Certainly twin study methods and the investigation of morphological variation can be expected to play an increasingly important role in human biology.

Appendices

APPENDIX I–A

The Study Procedure

All subjects were given study appointments at their convenience, and were registered as out-patients in the Vanderbilt Clinic of the Columbia-Presbyterian Medical Center A health history was obtained, and health status was determined by laboratory and medical study which included a complete physical examination by a staff physician, blood studies, urinalysis, and chest x-rays At the time of this examination, blood specimens were obtained for extensive blood grouping studies To assure the objective handling of data, all individuals were given code numbers for the identification of laboratory specimens, photographs, records, etc. (See sample forms on the following pages)

With only three exceptions, both members of every twin pair came in for simultaneous study While one member of a pair was being examined by the physician, the other was questioned and observed, and anthropometric measurements were taken All observations and measurements were made by the senior author At the time the second twin was observed and measured, no reference was made to the first twin's record Following the complete examination of both members of the twin pair, finger and palm impressions were taken, and the subjects were photographed in accordance with the method utilized by Sheldon (1954), as previously reported (Osborne, 1956).

Following this examination the subjects were asked to participate in further study. Tentative appointments were made for complete dental examination (Horowitz et al, 1958, Osborne et al, 1958) Early morning appointments were made for electrocardiographic and ballistocardiographic studies, and basal recordings were taken by Dr. James Mathers. These data are being prepared for publication. At the time of these studies, additional blood specimens were obtained for serum lipid determinations, which were carried out by Dr. David Adlersberg, at Mt Sinai Hospital (Osborne, Adlersberg, De George, and Wang, 1959).

Name ______ Age ______ Ward ______ Unit No. ______

DATE

PERSONAL HISTORY

BIRTH Gestation period ______ Duration of labor ______ Delivery ______

Weight ______ Injuries ______ Indications of lues ______ Convulsions ______

Remarks ______

EARLY DEVELOPMENT Nursing breast / bottle ______ First teeth ______ Sphincter training ______

Began to sit up ______ Began to stand ______ Began to walk ______ Began to talk ______

GENERAL HEALTH (Note energy, fatigability, regularity of mode of living) ______

HABITS AND FUNCTIONS, Diet ______ Tea ______ Coffee ______

Sleep ______

Vision R ______ L ______ Glasses ______ Why? ______

Hearing R ______ L ______ Tinnitus R ______ L ______

Weight Gain ______ lbs in ______ yrs. Loss ______ lbs in ______ yrs. Sexual ______

Tobacco ______ Drugs ______ Alcohol ______

SYSTEM REVIEW

Cardio-respiratory	Gastro-intestinal	Urinary	Neuro-muscular	Menses	
Cough	Appetite	Frequency	Convulsions	First occurrence	
Pain in chest	Digestion	Urgency	Fainting	Regularity	Interval
Hemoptysis	Abdominal pain	Pain	Headache	Duration	
Dyspnea	Constipation	Incontinence	Vertigo	Amount	
Orthopnea	Diarrhea	Nocturia	Nervous episodes	Dysmenorrhea	
Edema	Blood in stools	Nocturnal enuresis	Paralysis	Last occurrence	
	Thirst	Polyuria	Sensory difficulty	Menopause	

ILLNESSES (State age of occurrence)

Chicken Pox	Pertussis	Diabetes	Nephritis	Scarlet fever	Venereal—
Chorea	Poliomyelitis	Encephalitis	Neuritis	Sinusitis	chancroid
Diphtheria	Adenitis	Influenza	Otitis	Tonsillitis	gonorrhea
Measles	Cardiac	Malaria	Pneumonia	Tuberculosis	syphilis
Mumps	Common colds	Meningitis	Rheumatic fever	Typhoid fever	

Skin eruptions ______

Allergy (asthma, hay fever, food or drug idiosyncrasy) ______

Tumors ______

Other diseases ______

INJURIES Head fracture ______ unconsciousness ______ Bleeding from orifices nose ______ ear ______ mouth ______ Sequelae ______

Other Injuries ______

OPERATIONS ______

MARITAL Married at ______ yrs. Children L ______ D ______ Husband / Wife ______

Miscarriages ______

EDUCATION ______

OCCUPATION ______

FAMILY HISTORY

Consanguinity Twins Allergy

Hereditary trends, Systemic

Neurological or Psychiatric

Father

Mother

Brothers

Sisters

PHYSICAL EXAMINATION SHEET

Age________

Name____________________ Ward________ Unit No.________

DATE ________ WEIGHT _____ HEIGHT _____ TEMP _____ PULSE _____ RESP _____

SYMBOLS √ = Normal O = Absent X = Abnormal (to be described on reverse side of this sheet)

HABITUS	— w. d. and n.	— Color			
SKIN	— Warm	— Moist	— Pigmentation	— Lesions	— Hair
HEAD	— Size	— Shape		— Face	
Eyes	— Vision	— Prominence	— Conjunctivae	— Sclerae	— Fields
Pupils	— Equal	— Round	— React. light & distance	Extra Ocular Muscles	— Fundi
Ears	— Hearing	— Discharge	— Drums	— Mastoids	Sinuses F
Nose	— Obstruction	Discharge	— Polypi	Smell	— Sinuses M
Mouth	— Mucosa	— Lips	— Angles	Pigmentation	— Metal line
Tongue	— Surface	— Midline	— Tremor		Speech
Teeth	— Functionally Adequate	— Denture Upper	— Denture Lower	Tooth Pathology	Pyorrhea
Throat	— Color	— Exudate	— Pharynx	— Palate	— Voice
Tonsils	— Present	— Size	Surface	— Crypts	Exudate
Neck	— Inspection	Motion	— Veins	— Thyroid	Trachea
Lymph Nodes	— Cervical	— Axillary	— Inguinal	Epitrochlear	Supraclavicular
CHEST	— Shape	— Symmetry	Expansion		
Breasts	— Development	— Glandular consistency	Masses	— Nipples	
Heart	— Apex seen	— Felt	Thrills		
Sounds	— Regular	— Quality	— Murmers		
Pulses	— Equal	— Synchronous			
Lungs	— Resonant	Breath sounds	Rales		
	— Diaphragm Pos.	Diaphragm Excursion	Tactile Fremitus	Vocal Fremitus	
ABDOMEN	— Contour	— Scars	Soft	Tympanitic	Peristalsis
	— Tender	— Spasm	— Masses	Liver dullness	Edge not felt
	— Spleen not felt	— Kidney right felt	Kidney left not felt	— Costo-vertebral tenderness	— Hernia
Vagina	— Labia	— Clitoris	— Mucosa	— Perineum	— Discharge
Uterus	— Cervix	Fundus	Anterior Position	— Posterior Position	Mobility
Vaults	— Ovaries	— Masses	Tenderness	— Speculum	—
Rectum	— Hemorrhoids	— Sphincter tone	— Tenderness	— Masses	— Prostate
Male Gen.	— Penis	— Scrotum	Testicles	Epididymes	Cords
EXTREMITIES UPPER	— Strong	Coordinate	Tremor	Bones	— Joints
Circulation	— Color	— Radials	— Sweating	— Clubbing	— Vibration
EXTREMITIES LOWER	— Strong	— Coordinate	— Tremor	— Bones	— Joints
Circulation	— Color	— Veins	— Edema	— Vibration	—
	— Femoral	— Popliteal	— Dorsalis Pedis	— Posterior Tibial	—
Spine	— Scoliosis	— Kyphosis	Tenderness	— Spasm	— Motion
REFLEXES	— Biceps	— Triceps	— Radioperiosteal	— Hoffman	—
	— Knee Jerks	— Achilles	— Plantar	— Kernig	— Romberg
Sensory	— Tactile	— Pain	— Temp.	— Vibration	— Position
Mental—Emotional	— Intelligent	— Co-operative	— Oriented	— Emotionally Stable	—

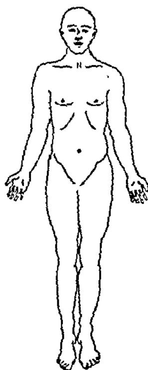
A₂	P₂
B P	R
	L
	LEG

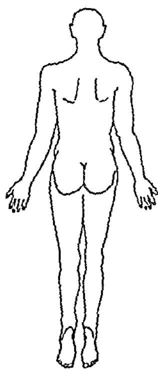
Cardiac Measurements

R		L
	1	
	2	
	3	
	4	
	5	
	6	

ABNORMAL AND IMPORTANT FINDINGS—SEE OVER

ABNORMAL AND IMPORTANT FINDINGS





LABORATORY REPORTS

Name ____________________ Series no. ____________ Date ____________

BLOOD TYPE

ABO D C E c MN S s K Fy^a P

BLOOD COUNTS

Hgb RBC WBC Neut. Eos. Baso. Lymph Mono. ESR

URINALYSIS

Sp. Gr. React. Alb Gluc. Acet. Casts Leuk. RBC Mucus

X-RAY

Posterior-Anterior, and Left Lateral chest plates

Name________________ Series no.________ Date________
Unit no.________ Mono __A______
Present add.________________ Perm. add.________ Dizy___B______

Phone________________
Sex______ Age______ Birth date________ Place____________ Gen. Amer______
Occupation________________ Age completed h. s.____ College______
Field of study________________
Marital status________ Age________ Age at birth of child (1)____ (2)______
(3)____ (4)______ (5)______ (6)____ (7)____

Health of Children ________________________________

Father (Relationship__________) Mother

Birthplace________________ Birthplace________________
Stock________________ Stock________________
Education________ Occup.________ Education________ Occup.________
Ht.________ Wt. history________ Ht.________ Wt. history________

Health________________ Health________________

Paternal Grandfather

Stock________________
Ht.________ Wt. history________
Health________________

Maternal Grandfather

Stock________________
Ht.________ Wt. History________
Health________________

Siblings

(Sex, age, ht, wt, health)________________________________

Twins birth rank__________ History of twins in family________________

Where raised________________________________
Degree of assoc. (parents' attitude, etc.)________________________________

Age first sep.________ Duration__________ Circumstances__________

Age perm. sep.__________ How far (degree etc.)________________

Development relative to twins________________________________

General health________________ Strength__________ Schol.________
__________ Who dominated________________
Additional remarks ________________________________

OBSERVATIONS

Name________________________No.______________Date______________

Hair

Whorls____
(Density: 0, 1, 2, 3, 4 Texture: Fine/F Medium/M Coarse/C

Head
Color: Black__Dk. br.__Med. br____Lt. br____Gold___White___
Red__Dk red___Med red____Lt. red____G. red____

Form. Str____Lt wave____Dp wave____Curly____Frizzy____

Texture________Density__________Balding________Graying__________

Face Color____
Lip___Cheek____Chin____Neck____Nose____Ear____
Eyebrows____________Eyelashes__________Eyebrow concur__________

Digits
Color__________   1______2______3______4______
First phalangeal   ______ ______ ______ ______
Second   "   ______ ______ ______ ______

Body Color____
Hand________________Forearm______________Upper arm__________
Lower leg________________________Upper leg________________
Hypergastric________________Thoracic______________________
Gluteal______________Lumosacral__________Lower back________Upper___

Freckles____
Sunburning (tanning)____

Eyes

Structure
Smooth________Eroded________Cryptose________Ridged____Scalloped______

Color
Background: Lt blue gray____Med blue____Dk blue____Med gray____Dk gray___
Med gr____Dk gr____Lt br____Med br_____Dk br________
Detail color: White____Yellow______Orange______Brown______Red brown______

Detail area: Absent____Small____Med____Large____Specks____Zoned______
Scallop darker____

- - - - - - - - - - - - - - - - -

Asymmetries:____

Hyperextension of the fingers_________________________________

OBSERVATIONS

Name__________ No. __________ Date__________

Ear

Lobe free (L)______ attached______ soldered______ Darwin's pt.______
(R)______ " ______ " ______ " ______
Helix (L)______ Protrusion______
(R)______ " ______

Teeth

Bite: Over______ Under______ Normal______ Corrected______

8 7 6 5 4 3 2 1   1 2 3 4 5 6 7 8

Chin

Type: Median______ Triangle______ Bilateral______ Projection______

PTC: water______ 25______ 50______ 100______ 400______ 800______
almaris longus left present______ absent______
right " ______ " ______
Peroneus tertius left present______ absent______
right " ______ " ______
Thumb hyperextension left______ degrees______
right______ " ______
Frontal hair type (1)______ (2)______ (3)______
Tongue rolling: Roller______ Non roller______

Second toe relative to first toe: Left______ Right______

Little finger______

Handedness______

Index finger rel. to ring finger: Left______ Right______

Iris rim______

BODY MEASUREMENTS

Name ____________________ No. __________

1 - Stature __________

3 - Arm length __________
4 - Bi-acrom. __________
5 - Bi-delt. __________
6 - Waist Bdth. __________
7 - Bi-iliac __________
8 - Hip Bdth __________
9 - Bi-troch. __________
10 - Chest Bdth __________
11 - Chest Depth __________
12 - Foot Lgth __________
13 - Foot Bdth __________
14 - Ankle Bdth __________
15 - Heel Bdth __________
16 - Humerus lgth __________
17 - Radius Lgth __________
18 - Hand Lgth __________
19 - Hand Bdth __________
20 - Mid-finger Lgth __________
21 - Wrist Bdth __________
22 - Wrist Min. Circ. __________
23 - Forearm Circ. __________
24 - Biceps Circ. __________
25 - Neck Circ. __________
26 - Neck Ant.-post. __________
27 - Neck Lateral __________
28 - Sitting Height __________
29 - Sittg. Supra-stl. __________
30 - Tib. Ht. __________
31 - Ankle Min. Circ. __________
32 - Calf Max. Circ. __________
33 - Knee Min. Dist. __________
34 - Knee Min. Prox. __________
35 - Thigh Circ. __________
36 - Hip Circ. __________
37 - Waist Min. Circ. __________
38 - Chest Circ. Nip. __________
39 - Chest Circ. Xiphoid __________

2 - Weight __________

1 - Head Circ. __________
2 - Head Lgth __________
3 - Head Bdth __________
4 - Min. Front. __________
5 - Bizygomatic __________
6 - Bigonial __________
7 - Total Face Ht. __________
8 - Upper Face Ht. __________
9 - Nose Ht. __________
10 - Nose Bdth. __________
11 - Int. Orb. __________
12 - Bi-orb. __________
13 - Mouth Wdth. __________
14 - Ear Ht. __________
15 - Head Ht. __________

Subcutaneous

Abdomen __________
Chest __________
Scapula __________
Upper arm __________
Thigh __________

Appendix I–B

Reasons for Exclusion of Twin Pairs from Analysis

Zygosity	*Sex*	*Reasons for exclusion*
MZ	♂ ♂	Poor general health since early childhood
DZ*		Under 18 years of age.
DZ	♀	Graves' disease
MZ	♀ ♀	Diabetes mellitus, thyrotoxicosis
MZ	♂	Poliomyelitis
MZ	♀	Endocrine disturbances
MZ	♀	Poliomyelitis
DZ	♀ ♀	Essential hypertension
MZ	♂ ♂	Endocrine disturbances.
MZ	♂	Under 18 years of age

REASONS FOR EXCLUDING TWINS

Zygosity	*Sex*	*Reasons for exclusion*
	♀	
MZ		Under 18 years of age, diabetes mellitus
	♀	
	♀	
DZ		Congenital heart defect
	♀	Severe hypertension
DZ	♀	Anorexia nervosa
	♂	Cancer of the lung †
MZ		Hypertensive vascular disease
	♂	
DZ	♀	Poor general health, severe gastrointestinal dysfunction
MZ	♀	Pregnant
MZ	♀	Endocrine disturbance
MZ	♀	Endocrine disturbances, anxiety neurosis
DZ*	♂	Very poor general health, questionable neoplasm †

* Dizygotic unlike sex pairs
† Detected at time of study

Appendix II

Zygosity Diagnosis

To avoid a circular type of reasoning in twin analysis, it is necessary to select criteria for the diagnosis of zygosity which do not directly correlate with, or reflect, the intrapair differences in the characters or traits under investigation Since the purpose of the present study was to examine complex or compound characters, principally those of gross morphology, it would have been inappropriate to base the diagnosis upon such attributes. A zygosity diagnosis should always be as objective as possible, this objectivity requires the use of criteria which exhibit clear cut differences, and the basing of the diagnosis upon a definitely established point of reliability.

Since, in a study of adults, reliable information about fetal membranes is unobtainable, and, for subjects in essentially good health, heteroplastic skin grafting is difficult to justify, the proved dizygotic method using only the more reliable characters for establishing intrapair differences was considered to be the most satisfactory method. The most objective characters at present available for establishing differences, sex and the blood group factors, were used as the basic diagnostic criteria.

Twenty cc. blood specimens were divided between sterile 10cc. Wassermann tubes, and the clots were immediately refrigerated Professional blood technicians in three different laboratories carried out all determinations, and all determinations were done at least twice, independently, to avoid the possibility of typing error

On the basis of these determinations, all like sex twin pairs were classified as being similar or having a difference in one or more of the factors tested

The blood of twins was tested for: A_1, A_2, B, O, M, N, S; C, D, E, c of the Rh series; Kell, Duffy, and P. A difference in any one of these blood factors was taken as sufficient proof that a like sex pair was dizygotic The question arose, however, as to the advisability of defining monozygotic twins as those like sex pairs with similar blood, and like sex dizygotic twins as those with dissimilar blood. In an earlier report (Osborne, 1956), the data were analyzed twice: first by means of a "blood and sex diagnosis," and then with the addition of other diagnostic criteria. The mean intrapair differences in both monozygotic and dizygotic twins were insignificantly affected by the second diagnosis, and, for by far the greater part, the use of the second diagnosis resulted in a more conservative test for a measurable genetic component of variability

When, in the extension of the adult twin series and in an additional study of a juvenile twin group, five unlike sex pairs were found to agree in all the blood factors tested, it became apparent that it would be necessary to extend the diagnostic criteria beyond sex and the blood factors

The addition of other diagnostic criteria present a number of difficult problems The majority of criteria which can be used have different diagnostic values in different populations, therefore, it is necessary to evaluate the usefulness of each criterion for the population studied Without making any reference to sex or blood group data, all of the observations listed in Appendix I–A were tabulated for all twin pairs studied For each characteristic the twin pairs were listed as being (1) definitely similar, (2) definitely dissimilar, or (3) similarity questionable When the sex and blood group data were then taken into consideration also, the characteristics which appeared most effectively to separate the pairs proved to be dizygotic on the basis of sex and blood were head hair color, eye color, eye detail pattern, tongue rolling, P T C. taste reaction, ear lobe form, chin form, and mid-phalangeal hair It should be emphasized that the relative value of these observations applies only to the present study, their usefulness in other studies will require independent evaluation

Following the selection of these diagnostic criteria, all like sex twin pairs agreeing in their blood factors were separated and reclassified as similar, dissimilar, or questionably similar for these eight criteria To be listed as similar, a twin pair had to be classified as similar for all eight criteria. To be listed as dissimilar, the pair had to be classified as dissimilar in two or more of these criteria, or as dissimilar in one and questionable in

three or more of the eight criteria All others were classified as questionable. On this basis ten pairs were classified as dissimilar and ten pairs as questionable

Although we had wanted to avoid use of dermatoglyphic patterns for establishing zygosity because we planned to utilize them in other aspects of the analysis, we decided that it would be advisable to determine whether this omission would in any way affect the diagnosis The dermal impressions were rated by the Brodhage and Wendt (1951) method for the entire adult and juvenile series, and total ridge counts were made for the 20 pairs in which zygosity was questioned A table of differences was then set up for both pattern analysis and ridge counts. We found no evidence that any of the three rating categories which had been assigned need be changed, and therefore concluded that accuracy in the diagnosis of zygosity was not sacrificed by the omission of dermatoglyphic characteristics

Further to assure that no information of diagnostic value was being omitted, we compared the facial characteristics in the photographs of all like sex twin pairs agreeing in blood factors, classifying them, on these obviously subjective grounds, into the same three groups. Again we found no reason to change the previous classifications. The ten like sex pairs agreeing in all blood factors but classified as dissimilar on the basis of the eight other criteria were therefore classified as dizygotic, and the ten questionable pairs were classified as monozygotic.

In employing a proved dizygotic method of zygosity diagnosis, a strict classification of the dizygotic twins is essential, and the possibility that extremely similar dizygotic twins may be classified as monozygotic must be accepted Any such error could result theoretically only in greater mean monozygotic variances If such an error has occurred in the present study, its effect would be small and it would be in the direction of a more conservative estimate of genetic influences.

Appendix III–A

Sample Somatotyping Card*

Subject No.

Osb. P.H. Age Sex Ht. Wt. P.I.

Scorer:

Total Rating:

Regional Ratings

Dysplasia: G-Index:

I

II

III

IV

V

Remarks:

Weight History

Weight

Age 18 22 26 30 36

* Card accompanying somatotype photograph for rating.

Appendix III–B

Data on Unrelated Controls

Table 91. Mean height (in inches) of unrelated controls by age*

		Northwest European				Jews			
	Age (years)	n	Mean	S E of mean	S D	n	Mean	S E of mean	S D
Males	18	357	70.37	.13	2.44	58	69.03	.27	2.04
	19	49	70.23	.38	2.63	16	67.94	.67	2.66
	20–26	138	70.40	.21	2.42	39	69.15	.38	2.34
	Total	544	70.36	.11	2.46	113	68.92	.21	2.26
Females	18	389	65.24	.17	3.33	133	63.52	.19	2.15
	19	294	64.89	.13	2.28	57	64.38	.26	1.97
	20–26	122	64.91	.22	2.41	13	63.35	.57	2.05
	Total	805	65.06	.10	2.86	203	63.75	.15	2.12

* See Chapter XII

Table 92. Mean weight (in pounds) of unrelated controls by age*

		Northwest European				Jews			
	Age (years)	*n*	*Mean*	*S E of mean*	*S D*	*n*	*Mean*	*S E of mean*	*S D*
Males	18	357	153 1	93	17.54	58	152 2	3 04	23 15
	19	49	159 2	2 86	20 02	16	151 6	5 91	23 65
	20–26	138	159 2	1 68	19 77	39	162 8	3 90	24 33
	Total	544	155 2	80	18 55	113	153 8	2 26	23 97
Females	18	389	129 1	83	16 36	133	126 2	1 42	16 32
	19	294	127 0	90	15 47	57	130 7	2 44	18 38
	20–26	122	128 6	1 40	15 43	13	125 4	5 47	19 73
	Total	805	128 2	56	15 91	203	127 4	1 21	17 18

* See Chapter XII

Appendix IV

Masculinity and Femininity Rating Method

The assessment of a man's masculine component, or of a woman's feminine component, as expressed morphologically, is based upon the relative development of different characteristics within the individual physique, not upon the individual's size, fatness, or muscularity in relation to the full range of human variation in these variables A small man can be just as masculine as a large, massively muscled man, a woman need not be fat to be feminine To assist in assigning scores independent of size or massiveness, all visual examples in Figures 1 and 2 (inside back cover) are drawn to the same scale An attempt has been made to describe the shape of the different segments and their development within the particular physique, rather than in terms of size or relative dimensions

In rating sexual morphology, care must be taken not to be prejudiced by the amount of breast development, abundance of body hair, or size of genitalia. While these characters obviously have sexual significance, they are variables which are subject to specific genetic and environmental modification, and which require evaluation on a very different basis.

The standards for assigning different point scores are provided by the examples, and the word descriptions are primarily a check list of the variables to be observed. It must be borne in mind in applying this method that few individuals will match these examples and criteria; the scorer must

determine whether a particular characteristic in the individual under study is greater or less than in these examples The scoring sheet is given in Table 88 The adjustment of score for shoulder-hip ratio, Table 89, is to be applied whenever appropriate

MALE

Class I (5 points)

Upper body

Upper extremity. The arm is tapered from shoulder to wrist rather than angular. The proximal segment is round with no lateral flattening There is an indication of both hyperextension and a carrying angle.

Trunk proportions There is no obvious dominance of the upper trunk, and the thorax is round rather than flattened. As measured by a straightedge from the axillary apex in posterior view, the shoulders are not wider than the hips. If the shoulders are narrower than the hips by 1 mm or more, ten points are subtracted from the upper body score.

Waist. There is a definable waist constriction and the angle formed by the iliac fat pad or pelvic brim is sharper than the angle formed by the rib cage.

Abdomen The abdominal surface is large and there is a definite protuberance below the umbilicus or waist constriction

Lower body

Buttocks The large curved buttocks appear as the most important aspect of the physique in the posterior view. There is no lateral dimpling or depression of the buttocks, there is no iliac line, and the buttocks extend from the gluteal fold to the waist line The gluteal groove is long

Trochanteric pads and hip line There is a definite sub-trochanteric fat pad, and if there is a roll at the iliac crest, it forms a double hip curve with the narrowest point at the head of the trochanter

Thigh The front of the thigh is padded, curved, and without muscle relief The thighs are tapered cones, and in the moderately obese are closely approximated. In the thin individuals the inner surfaces of the thighs are concave and the knees are in contact The patella is small and not prominent

Lower leg Both the inner and outer surfaces taper to inconspicuous malleoli

Class II (15 points)

Upper body

Upper extremity The upper and lower arm shows some molding rather than being predominantly tapered. The proximal segment is essentially round rather than flattened laterally. If any hyperextension is present, it

should be accompanied by some observable development of the triceps. The curve of the shoulder is smooth, rather than abrupt or angular.

Trunk proportions The lower trunk is large and there is no really impressive excess of chest The sternum appears somewhat short, and there may be even some constriction of the lower rib cage. The thorax is not markedly flattened anterior-posteriorly, and the hips are approximately the same width as the shoulders, as measured from the axillary apex

Waist The waist line is not constricted, but it is high and the lower angle is pronounced, more so than the angle formed by the rib cage

Abdomen The protuberance below the umbilicus is not abrupt, although the abdomen is relatively spacious and indications of Paupart's ligament are only slightly visible There is no strong abdominal musculature evident.

Lower body

Buttocks The buttocks are large and predominantly curved, although there may be a hint of lateral dimpling, and there is no iliac furrow, but the buttocks do not appear to be continuous with or include the flank.

Trochanteric pads and hip line. While there is a sub-trochanteric curve, there is no clearly delineated pad and only a hint of a double curve is present. The narrowest point of the pelvis obviously lies above, rather than at, the head of the trochanter

Thigh. The front of the thigh has sufficient padding largely to mask muscle relief. The thighs are more tapered than cylindrical, and are in contact part of the distance, although the knees are separated.

Lower leg. The lower leg is more angular than tapered, and while there is a well defined inner curve, it is little more than equal to the outer curve.

Class III (25 points)

Upper body

Upper extremity. The arm is of good length, and the proximal segment is obviously flattened laterally. There is no appearance of tapering, and molding is clear in both upper and lower segments. The curve off the shoulder is broken from deltoid to biceps.

Trunk proportions. The thorax is definitely dominant over the abdomen and there is some obvious anterior-posterior flattening. The shoulders are wider than the hips, as measured from a line dropped from the axillary apex.

Waist The waist does not have a high appearance, it is flattened without a constriction or obvious point of least circumference.

Abdomen. The abdominal musculature appears strong or hard; Poupart's ligament is clearly seen There is no indication of a delineation between the abdomen and a pubic pad

Lower body

Buttocks. The buttocks are of only moderate size, and are compact

rather than soft-appearing. There is lateral dimpling, the gluteal groove is of moderate length, and the iliac furrow is well developed, so that the buttocks do not appear to extend even to the level of the iliac crest

Trochanteric pads and hip line. There is no sub-trochanteric curve and the widest point of the pelvis is either at the head of the trochanter or at the iliac crest What may resemble a double hip curve is actually formed by bone or muscle; its narrowest point is well up toward the iliac crest

Thigh. There is no strong indication of padding and the thighs appear to be predominantly muscular. The thighs are cylindrical rather than cone shaped, and the knees are not in contact, although the thighs may be in contact if the musculature is massive. The patella is large and obvious

Lower leg There is no indication of taper. The inner surface is strongly molded and is greater than the outer curve.

Class IV (35 points)

Upper body

Upper extremity The arm is relatively long, the proximal segment is well flattened laterally, and muscle relief is clearly observable The upper portion of the forearm is well developed

Trunk proportions The thorax is long and flattened with pronounced widening of the upper chest cage. There is no constriction of the lower ribs.

Waist The waist is low and long, and the upper portion meets the lower rib cage at a sharper angle than that formed by the pelvic brim

Abdomen The abdomen is flat and hard with strong ligaments The musculature of the abdomen clearly carries to the pubic bone, and there is no delineation of a soft umbilical pad on the pubic area

Lower body

Buttocks The buttocks appear small relative to the shoulders and upper back They are square or rectangular with well marked lateral compression rather than mere dimpling The iliac furrow is clearly defined

Trochanteric pads and hip line The widest point is the head of the trochanter; any roll or pad at the crest definitely appears to lie above the point of attachment of Poupart's ligament and the iliac furrow The latter may even give the appearance of a depression at the iliac crest.

Thigh The thighs are hard and rectangular, with marked definition of muscle, whether massive or not The knees appear to be bowed, the patellae are large and obvious with muscle definition above

Lower leg The lower leg is strongly molded and the angle at the ankle is sharp, the malleoli are large and prominant

Class V (45 points)

Upper body

Upper extremity The arm is long and muscle definition clear, there is extreme lateral flattening of the upper segment The wrist appears wide, but the proximal portion of the forearm is abruptly widened

Trunk proportions The thorax completely dominates the abdomen and the chest breadth greatly exceeds the chest depth. If the chest breadth as measured at the axillary apex is greater than the hip breadth by more than 2 mm , ten points are added to the upper body score

Waist The long low waist is essentially without a lower border formed by the pelvic brim, while the rib cage comes in at a sharp angle due to the relatively greater breadth of the thorax

Abdomen The abdomen has a small flat surface area relative to the upper trunk, and Poupart's ligaments form a small angle at the pubic bone Muscle relief is clearly seen

Lower body

Buttocks. The buttocks appear almost too small for the expanse of the upper back and shoulders. They are hard and angular with deep lateral depressions. The iliac furrow is well developed and the gluteus maximus muscles appear to cover but a comparatively small portion of the pelvic region.

Trochanteric pads and hip line The widest point of the nearly solid curve is at the level of the head of the trochanter. The pelvis, in all dimensions, appears small relative to the trunk above it.

Thigh. The rectangular thighs have a greater lateral than anterior-posterior diameter. Any contact on the inner surfaces of the thighs is obviously due to muscle, and muscle definition is apparent in all three views

Lower leg The curve of the inner calf is extremely angular, and there is clear muscle and bone delineation. The tendons at the large malleoli are clearly seen.

FEMALE

Class I (5 points)

Upper body

Upper extremity There is no indication of hyperextension or development of a carrying-angle Definite muscle relief and angularity rather than taper are present. The upper arm is flattened laterally, and the forearm is strongly molded.

Trunk proportions Shoulders and chest cage dominate the trunk The upper chest is markedly broad; the entire thorax is long and relatively flat.

Waist The waist is low, emphasizing the dominance of the upper trunk over the lower trunk. There is no abrupt waist angle and the rib cage

forms a sharper angle than that formed by the pelvis (In obese individuals, the fat roll is clearly above the iliac crest.)

Abdomen The abdomen appears flat and hard, and there is muscle definition. If lines of the groin are apparent, they extend to the pubic symphysis, rather than meeting above to form a "line of Venus"

Lower body

Buttocks The buttocks are small and compact, and appear rectangular rather than round and soft. There is strong indication of lateral dimpling, there may even be an iliac furrow, so the buttocks do not extend beyond the level of the iliac crest

Trochanteric pads and hip line Only a sub-trochanteric curve is present, rather than a fat pad If a double curve is seen, it is of the male type. the narrowest point is above the head of the trochanter. The hips are no wider than the upper trunk as measured from the axillary apex; if the hips are narrower by more than 1 mm, ten points are subtracted from the lower body score

Thigh. The front of the thigh (side pose) is relatively straight. The thigh gives little indication of taper, being essentially cylindrical The lower parts of the thighs are widely separated, and the knees suggest bowing.

Lower leg. The lower leg is strongly and quite sharply molded; the inner curve exceeds the outer curve.

Class II (15 points)

Upper body

Upper extremity. While there is no hyperextension, and no definite carrying angle, the line off the shoulder is relatively smooth. Muscle definition is not entirely obliterated; upper arm shows some indication of lateral flattening, and the forearm can be described as more tapered than molded.

Trunk proportions. Shoulders and thorax are well developed, and while the upper chest cage appears relatively wide, the lower portion is constricted laterally, as seen in the anterior and posterior views.

Waist. The waist may be well defined, but the angle formed by the pelvis is no sharper than the angle formed by the rib cage.

Abdomen There may be some abdominal musculature apparent, but the surface of the abdomen is smoothly curved with some protuberance below the umbilicus

Lower body

Buttocks. Though the buttocks are curved rather than rectangular, they are compact, there may be only the faintest indication of lateral flattening The sacral triangle is clearly seen, and the buttocks, while tapered off to the waist, are not conspicuously continuous with the flank.

Trochanteric pads and hip line. There is small but discernible development of trochanteric pads, and the hip

curve, while of the female type, is only slightly defined Only the trochanteric pads or only a small portion of the hips is wider than the axillary apex.

Thighs There is some curve to the anterior thigh (side pose), but this curve extends unbroken to the groove of the groin; there is only the slightest suggestion of taper towards the knee. Knees are neither bowed nor approximated

Lower leg Inner as well as outer surface is well curved, but not angular

Class III (25 points)

Upper body

Upper extremity There is an indication of either some hyperextension or carrying-angle, and the curve off the shoulder is smooth There is no evidence of lateral flattening or muscle definition

Trunk proportions While the shoulders and upper thorax do not have a constricted appearance, upper and lower trunk appear to be more or less in balance The thorax gives no impression of anterior-posterior flatness

Waist The waist line is obviously well above the iliac crest, contributing to a balance between the upper and lower trunk While the lower angle is not abrupt, it is sharper than the angle formed by the rib cage

Abdomen The soft curve of the abdomen is not broken by any muscle definition, and the protuberance below the umbilicus gives an indication that the lines of the groin meet above the pubic symphysis.

Lower body

Buttocks The buttocks are moderately large and predominantly curved and continuous with the flank. There is no indication of lateral flattening

Trochanteric pads and hip line The trochanteric pads are clearly developed and there is a smooth but definite double hip curve. The full hip line to the narrowest point of the iliac curve is slightly wider than the axillary apex.

Thighs The anterior surface of the thigh is well curved, there may be some indication of a skin crease The thighs definitely taper toward the knees, and the knees angle inward and are in contact. If the thighs are lean, the inner surface is concave with a soft convexity above.

Lower leg While there may be an obvious curve to both the inner and outer surfaces, these curves are smooth and taper toward the ankle.

Class IV (35 points)

Upper body

Upper extremity There is definite but not extreme hyperextension and/or some indication of a carrying-angle Both the upper and lower arm are essentially round and tapered

Trunk proportions. The upper trunk appears somewhat small relative to the lower trunk. The thoracic cage is definitely rounded.

Waist The waist has a "pinched-in" appearance, and, particularly in the posterior pose, appears high The lower angle is sharper and somewhat more abrupt than the upper angle

Abdomen The protuberance below the umbilicus is so evident that the grooves of the groin carry across the abdomen above the pubic area.

Lower body

Buttocks The large soft buttocks extend from the gluteal fold to the waist without interruption The sacral triangle, which may even be slightly mounded and indicated only by the dimples at the superior iliac spines, appears to be short and wide

Trochanteric pads and hip line The trochanteric pads are large and the double hip curve is strongly developed The full hip line, including the major part of the curve of the iliac crest, is wider than the axillary apex

Thighs The anterior thigh is strongly curved and a skin crease is usually present There is a marked taper toward the knees, the thighs and knees definitely slant inward

Lower leg The outer curve is greater than the inner curve, and there is marked taper

Class V (45 points)

Upper body

Upper extremity There is extreme hyperextension or an exaggerated carrying-angle The arm is round and tapered from shoulder to wrist

Trunk proportions The lower trunk definitely dominates the upper trunk The thorax is round and narrow with very little taper

Waist The waist is high and sharply defined, giving the impression that the small upper body is set upon a well-developed lower body

Abdomen The protuberance below the umbilicus is well developed or abrupt, and the grooves of the groins meet to demarcate clearly the pubic area

Lower body

Buttocks The buttocks clearly dominate the physique in the posterior view, and are large, curved, and continuous from fold to flank The sacral triangle, which is either deeply dimpled or mounded, is short and wide

Trochanteric pads and hip line The trochanteric pads and the entire double hip curves are exaggerated. The trochanteric pads are continuous with the upper portion of the hip curve If the hips or trochanteric pads exceed the width of the axillary apex by more than 2 mm., add ten points to the lower body score.

Thighs The anterior surface of the thigh is pronouncedly curved from skin crease to knee The inner surfaces of the tapered thigh are in contact to the knees

Lower leg The inner and outer surfaces are essentially straight, tapering into the ankle.

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